# MULTIPURPOSE TREE PRUNINGS AS A SOURCE OF NITROGEN TO MAIZE (*Zea mays* L.) UNDER SEMIARID CONDITIONS IN ZIMBABWE

By

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To my late father, Mack Ruzive Josiah Mafongoya, who passed away on October 22, 1992, while I was in Gainesville writing my Ph.D. qualifying examinations. Tinotenda nebasa ramakatiitira musharukwa, Mutape!!

Leviticus 25:1-7 "Land also needs a Sabbath rest every seventh year" for soil fertility regeneration.

And to my lovely mother Dudzai Mary Mafongoya.

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MULTIPURPOSE TREE PRUNINGS AS A SOURCE OF NITROGEN TO MAIZE (*Zea mays* L.) UNDER SEMIARID CONDITIONS IN ZIMBABWE

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Prunings of multipurpose trees (MPTs) are used in the tropics as a source of nitrogen to maize. However, research results have shown that nitrogen recovery (NIR) from the prunings so used is generally low, the main reason being possible asynchrony between N supply by prunings and demand for N by the crop. NIR could possibly be improved if N release is synchronized to crop N demand either by modifying the method and timing of pruning application or by using prunings of different quality with varying N release patterns.

NIR of MPT prunings as a source of nitrogen to maize was studied in a series of field and pot experiments. Seven MPT species commonly found in agroforestry systems were used. The objectives of the study were to

(1) evaluate the effect of chemical composition of MPT prunings on their decomposition and N release patterns, and

(2) study interactions of pruning quality, method and time of pruning application and soil type on NIR by maize.

The nitrogen release patterns of various prunings were related to their chemical composition. Cumulative nitrogen released over time was correlated with % lignin, % NDF-N, polyphenol:N ratio, and (lignin + polyphenol):N ratio. Nitrogen release patterns from MPT prunings can be predicted using polyphenol:N and (lignin + polyphenol):N ratios as indices of chemical quality of prunings.

Incorporating prunings gave higher nitrogen uptake, NIR and maize grain yield, compared to surface application, for most of the species. Application of prunings at planting gave higher NIR than application 2 or 4 weeks after planting maize. However, prunings applied 4 weeks after maize emergence resulted in higher NIR by the subsequent crop than those applied at planting. This result was dependent on species, soil type and application method.

There was no difference in NIR from splitting the application of prunings, half at planting and half 2 or 4 weeks later, compared to one-time application at either time. Mixing of prunings of different MPT species did not improve NIR compared to each species applied alone under field conditions. This study has shown that NIR of prunings as a source of N to maize can be improved by managing

pruning quality and the time and method of pruning application. Farmers can manipulate one or more of these factors in order to make maximum benefit of MPT prunings as an organic fertilizer resource.

# CHAPTER 1
# GENERAL INTRODUCTION

Shifting cultivation of one form or another has been and continues to be the main farming system in most parts of Africa. Traditionally this system involved clearing the land of woody vegetation followed by cultivation of crops for a few (3-5) years (cropping phase). The fields would then be abandoned to natural fallow for a variable period of up to 20 years (fallow phase), during which time soil fertility would regenerate (Nye and Greenland 1960). However, human population growth rates of about 3% per year for the past two decades (Population Reference Bureau 1995) have resulted in the shortening of fallow periods in shifting cultivation cycles. Due to this increased land pressure, marginal lands with low soil fertility are also being brought into cultivation. As a consequence, crop yields and per capita food production have declined in most parts of post-colonial Africa (Brown et al. 1995). In sub-Saharan Africa, indeed in many developing areas of the tropics, it is no longer possible to maintain long fallow periods for soil fertility regeneration (FAO 1990).

Chemical fertilizers could be used to maintain soil fertility and increase crop yields. However, use of

fertilizers has not been widely adopted by small-scale farmers for a number of reasons, the most important being the lack of timely availability and the relatively high cost (Vlek 1990). Most developing countries have been implementing economic structural adjustment programs. A major activity of such programs is removal of economic subsidies on farm inputs like chemical fertilizers. Consequently, prices of fertilizers are beyond the economic means of small-scale farmers. Application of cattle manure is another widely used means of maintaining soil fertility and crop productivity. However, in most cases, the quantity of manure applied is too low to be effective in attaining these objectives (Batiano and Mokwunye 1991).

Therefore, there is an urgent need to develop alternative low-input strategies for soil fertility management based primarily on locally available biological resources. Since the 1980s, there has been considerable interest in low-input technologies, such as agroforestry systems and green manuring, as a means of soil fertility maintenance (Mulongoy and Akobundu 1992; Nair 1984, 1993; ICRAF 1992). As nitrogen (N) is the most limiting nutrient to crop production in the tropics, the use of leguminous species in the crop production systems may help meet the N requirement of crops. Agroforestry technologies, such as alley cropping, improved fallow, and biomass transfer involving leguminous trees and shrubs, have been developed

and tested under several tropical conditions as alternatives to shifting cultivation and maintenance of soil fertility (Kang et al. 1990; ICRAF 1992; Nair 1993).

In alley cropping systems, multipurpose trees (MPTs), usually legumes, are planted as hedgerows in crop production fields. The hedges are pruned periodically and the prunings (leaves plus small twigs) are returned to the soil as mulch and green manure, as sources of nutrients to the companion crops grown in the alleys. Prunings of various hedgerow trees have been shown to increase maize grain yields to the same level as application of fertilizer N up to 90-100 kg $ha^{-1}$ in subhumid Nigeria on an alfisol (Kang et al. 1990). Kang and Duguma (1985) have shown from a long-term experiment over a six-year period that maize yield can be sustained around 2.0 t $ha^{-1}$ in alley cropping, but maize yield declined to 0.5 t $ha^{-1}$ in plots without application of prunings, under the same conditions.

Most of the results with alley cropping have been obtained in the humid tropics (Yamoah et al. 1986; Kang et al. 1990). However, the technology has not been very successful in increasing soil fertility and crop yields in the semiarid tropics. In the humid tropics, mulch yields as high as 8-10 t $ha^{-1}$ $yr^{-1}$ are obtained (Ong 1994) but rates of decomposition are high, making nutrients available to companion crops for only a short period of time (Budelman 1988). Potential crop response to pruning application could

be high. In the semiarid tropics, mulch yields from alley cropping are as low as 2-5 t $ha^{-1}$ $yr^{-1}$ (Jama et al. In Press) and there is competition between the hedgerow species and the companion crop for nutrients and water. These may limit the potential of alley cropping to improve fertility and productivity of soils in these regions.

In such cases, a biomass transfer system might be more beneficial than alley cropping (ICRAF 1992; Jama et al. In Press). This system involves planting MPT species outside the crop fields to avoid competition between crops and the trees. The trees are regularly pruned and the mulch is transferred and applied as a source of nutrients to the crops in separate fields. Mulch yield from this system has been found to be higher than for alley cropping (Jama et al. In Press). However, except for the work done by Mulongoy and van der Meersh (1988) on an alfisol in subhumid southern Nigeria, there have been few studies examining nitrogen use efficiency (NUE) of biomass transfer systems.

Improved planted fallow system is another agroforestry technology that is reported to improve crop production and maintain soil fertility (Balasubramanian and Sekayange 1992; Kwesiga and Coe 1994). In this system, after "abandoning" the land as in the case of shifting cultivation, short-duration leguminous trees and shrubs are planted for a period of 1-3 years to accelerate the rate of soil-fertility improvement during the fallow phase. *Sesbania sesban* (L.)

Merr. and *Tephrosia vogelii* Hook. f. fallows for a year or more have been shown to contribute 17-40 kg N $ha^{-1}$ to associated non-legume crops (Balasubramanian and Sekayange 1992).

Another option to accelerate soil fertility regeneration during fallow periods might be to plant a green manure crop such as an herbaceous legume (e.g., *Mucuna* spp.). The biomass of the green manure crop can be left on the surface as a mulch or incorporated into the soil before planting the next crop. Annual dry matter yields of these green manure crops can range from 1.5 to 7.5 t $ha^{-1}$ with N yields ranging from 30 to 300 kg $ha^{-1}$ $yr^{-1}$ (Akobundu and Okigbo 1984).

Prunings of leguminous MPTs used in alley cropping, improved fallow, biomass transfer systems, and herbaceous legumes used in green manuring have been shown to increase yields of various crops under subhumid conditions on alfisols in Nigeria (Mulongoy and Akobundu 1992). This is in part attributable to their N contribution (Yamoah et al. 1986), calculated as the difference between N uptake in plots supplied with and without prunings. N contribution to the associated crop has been very low, in the range of 40 kg N $ha^{-1}$ (Mulongoy 1986; Kang 1988; Mulongoy and van der Meersh 1988). This represents a nitrogen recovery (NIR) of less than 30%. In this study, I define NIR as

$$NIR = \frac{N\ uptake\ treatment - N\ uptake\ control}{N\ applied} \times 100\%$$

where "N uptake in treatment" refers to treatments where prunings have been applied and "N uptake in control" is where prunings are not applied. "N applied" is the amount of N applied in the prunings. The low NIR from prunings is probably due to lack of synchronization between crop (maize) N demand and release of N from prunings. Factors that should be considered to improve NIR include pruning quality and quantity, and the time and method of pruning application (Young 1989; Nair 1993; Myers et al. 1994).

The term "pruning quality" refers to the chemical composition of the prunings. Prunings of high quality are high in N and low in lignin, C:N ratio, and polyphenols (Young 1989; Nair 1993). High quality prunings decompose and release nutrients rapidly. Prunings that are low in N, high in lignin and polyphenols, and release nutrients slowly or immobilize N are considered to be of low quality (Myers et al. 1994). Prunings from MPTs used in agroforestry systems vary widely in their decomposition and nutrient release patterns (Palm and Sanchez 1990, 1991). This implies that agroforestry systems in which prunings are applied as a source of nutrients to crops can potentially be managed to achieve synchrony between crop-nutrient demands and pruning-nutrient release. Selection of appropriate MPT species, which differ in pruning quality, and management practices

such as time and method of pruning application will therefore be an important consideration.

The concept that nutrient release and crop uptake can be synchronized to some degree through management practices is one of the basic hypotheses being tested by the Tropical Soil Biology and Fertility Programme (TSBF) (Swift 1987). This program has found that factors which control decomposition and nutrient release include climatic factors such as rainfall and temperature, soil texture, and the quality and quantity of prunings and placement methods (Szott and Kass 1993). Meentemeyer (1978) suggested that in the tropics the rate of decomposition is controlled more by litter quality than climate. N mineralization from MPT prunings in the short term (less than 6 months) has been negatively correlated with C:N ratio, polyphenol concentration, lignin:N, polyphenol:N and (lignin + polyphenol):N ratios under both field and laboratory conditions (Fox et al. 1990; Palm and Sanchez 1990, 1991; Tian et al. 1992a). This suggests that MPT prunings may not be good sources of available N to crops despite their high N content due to high concentration of polyphenol and lignin.

In the research presented here, it is hypothesized that MPT pruning quality, time of pruning application, and method of pruning placement can be managed to improve the NIR from MPT prunings as a source of N to a maize crop in the semiarid agroecological zone of Zimbabwe.

The main objectives of this study are the following:

1. To determine if MPT prunings differ in their chemical composition, and if and how these differences are related to their N mineralization patterns.

2. To evaluate the effects of MPT pruning quality, and the time and method of pruning application on NIR by maize.

3. To study the interaction of MPT pruning quality, time and method of application, and soil type on NIR by maize.

The study is presented in six chapters. Following this introductory chapter (Chapter 1), Chapter 2 discusses MPT pruning quality and its relationship with N mineralization patterns of various MPT prunings. Results of a field experiment conducted to evaluate the effect of MPT pruning quality and method of pruning application on NIR are presented in Chapter 3. Chapter 4, based on another field experiment, evaluates the effects of time of pruning application on NIR by maize. The interaction of MPT pruning quality, time and method of pruning application, and soil type on NIR by maize, studied in a greenhouse experiment, is presented in Chapter 5. Chapter 6 is the concluding chapter, and provides a summary of the main findings, general conclusions, and areas for future research.

## CHAPTER 2
## NITROGEN MINERALIZATION FROM MPT PRUNINGS AS INFLUENCED BY THEIR CHEMICAL COMPOSITION

### Introduction

Screening of leguminous multipurpose tree (MPT) species for potential use in agroforestry systems has been a major part of agroforestry research and development for the past two decades (Nair 1993). Among the several species tried, *Leucaena leucocephala* (Lam.) DeWit (hereafter leucaena) has been the most widely tested for biomass and N production, especially for alley cropping systems (Kang et al. 1990). However, the potential of leucaena is not fully realized in acid soils which comprise more than 50% of soil types found in the humid, subhumid, and semiarid tropics (Sanchez 1976). Moreover the recent widespread incidence of the psyllid pest (*Heteropsylla cubana*) has threatened the use of leucaena in many agroforestry systems. This highlights the need for a diverse range of MPT species to be used in agroforestry systems. Researchers have identified several MPT species adapted to infertile acid soils in the semiarid zones of southern Africa (ICRAF 1992). These include *Gliricidia sepium* (Jacq.) Walp., *Flemingia macrophylla* (Willd.) Merr., *Acacia angustissima* (Mill.) Kuntze, *Calliandra calothyrsus*

Meissner, *Sesbania sesban*, and perennial *Cajanus cajan* (L.) Millsp. These MPTs are used to maintain soil fertility in a variety of agroforestry systems such as alley cropping, improved fallow, and biomass transfer systems (ICRAF 1992). The choice of MPT species will depend upon the particular agroforestry system being developed and on species characteristics such as biomass production, response to pruning, N concentration, and rate of decomposition and N mineralization. The latter two, rates of decomposition and N mineralization of MPT prunings, depend in part on the chemical composition of the materials (Swift et al. 1979). However, very little is known about the chemical composition of MPT species grown in semiarid conditions and the effect of chemical composition on their N mineralization potential.

The decomposition of MPT prunings can affect crop growth directly through mineralization of N and indirectly through build up of soil organic matter (SOM). High quality prunings that decompose rapidly and are high in plant nutrients may contribute to enhanced crop growth by supplying N to the standing crop while slowly decomposing prunings may build up SOM. Information on the rate of decomposition and N mineralization of various plant residues is needed in order to predict the results expected from application of a particular MPT's prunings and litter, and to design cropping systems with efficient nutrient supply and satisfactory SOM build up. Another important

consideration would be to determine if the time and rate of N release can be synchronized with crop N demand. The degree of synchrony is important for efficient N use under conditions of high rainfall or shallow-rooted crops (Handayanto et al. 1992).

Synchrony can be achieved by manipulation of pruning quality (Swift 1987). If low-quality prunings are applied at the onset of the rains, they may immobilize N and release it later when the crop has greater demand for N. In the case of high quality prunings, N may be released rapidly in excess of plant demand. However, application of a mixture of high- and low-quality prunings is potentially able to achieve better synchrony, which will result in increased crop yield and less nutrient loss. However, there is very little experimental evidence to support this hypothesis.

In order to manage short- and long-term N availability to crops from organic inputs, there is a need to understand N mineralization and immobilization patterns, which in turn depend to a large extent on the chemical composition of the plant tissues (Swift et al. 1979). The C:N ratios or N concentration has been shown to be a good predictor of N mineralization rate. Decomposing materials with N concentration of less than 1.73% and C:N ratio > 25 were shown to immobilize N, whereas plant material with an N concentration > 2% and C:N ratio < 25 would lead to rapid release of N (Frankenberger and Abdelmagid 1985). However,

most of such work has been done with biomass of herbaceous legumes used as green manures. There are other modifying factors, such as lignin and polyphenol concentration, which will determine whether N will be released or immobilized (Vallis and Jones 1973). Prunings of leguminous MPTs with high concentrations of lignin or polyphenols seem not to conform to the general pattern of decomposition noted above. Studies by Palm and Sanchez (1991) and Fox et al. (1990) have shown that leguminous MPT residues, despite their high N concentration, can lead to N immobilization for several weeks. Lignin or lignin:N ratio provided good prediction of N release from non-leguminous tree litter (Melillo et al. 1982). However, there has been no agreement on the best predictor of N mineralization from leguminous plant residues. While Fox et al. (1990) found (lignin + polyphenol):N ratio was a "good" predictor, Palm and Sanchez (1991) found polyphenol:N ratio was a "better" one. Most such research has been done with plant materials in humid tropics which may be expected to have low levels of polyphenols (McClure 1979; Muller et al. 1987). Biomass of trees grown in semiarid conditions on acid soil is expected to have higher concentration of polyphenols due to increased acidity and moisture stress (Muller et al. 1987) and this may have an influence on the relative value of these indices as predictors of N release dynamics. Correlation between chemical composition indices and N mineralization could be

used to screen candidate species, optimize management practices, and gain insight into ecosystem functioning.

Under these circumstances, the study reported here was conducted to determine if N mineralization from MPT prunings is correlated to various chemical composition indices of the MPT species. The specific objectives of the experiment were the following:

1. to determine the range of nitrogen, lignin, and polyphenols in the leaves of various MPTs;
2. to examine the relationship between these chemical composition indices and N mineralization patterns.

## Materials and Methods

A laboratory incubation experiment using leaves of seven MPTs commonly used in agroforestry systems in Zimbabwe was conducted in a controlled environment at the University of Florida.

### Plant Samples

Prunings, consisting of leaves only, were cut from various MPTs grown at the International Centre for Research in Agroforestry (ICRAF) Domboshava research site in Zimbabwe at the end of the rainy season in 1993. These samples were collected from a replicated trial where several MPTs were being screened for local adaptability. The MPTs were *Acacia angustissima*, *Calliandra calothyrsus*, *Flemingia macrophylla*, *Cajanus cajan*, *Gliricidia sepium*, and *Leucaena leucocephala*

(Table 2.1). The prunings were sun dried for 2-3 days on a concrete floor. Samples were oven dried at 65° C for 48 hr to determine the dry matter (DM) content. Results of the chemical analysis are expressed on a % DM basis. The plant materials were analyzed for C, N, neutral detergent fiber N (NDF-N), soluble polyphenols, insoluble proanthocyanidins, and lignin. Total N was determined by micro Kjeldahl and NDF-N by micro Kjeldahl on NDF fraction, lignin by the acid detergent fiber method (Goering and van Soest 1970), and soluble polyphenols by gravimetric method of precipitation with trivalent ytterbium acetate (Reed et al. 1985). Insoluble proanthocyanidins in NDF were determined by heating NDF (5 mg at 95° C for 1 hr) in N-butanol (5 ml) containing concentrated HCl (5% V/V) (Reed et al. 1982). Organic carbon in the leaves was determined by the Dumas mass combustion method.

## Laboratory Incubation Procedure

The nine MPT pruning samples were ground to pass through 1-mm mesh then added at the rate of 150 mg/30 g of soil; the soil characteristics are described later. The soil was air dried and sieved also to pass through a 2-mm mesh. The prunings and soil were thoroughly mixed and put into polyethylene bags. Distilled water was added to the soil to achieve a moisture content of 50% of water holding capacity by weight, a moisture content chosen to allow maximum

microbial growth. In the control treatment, no prunings were added to the soil. The incubation bags were sealed and put in the incubator maintained at 28° C through the experiment period. Moisture content of the incubated soil was maintained at 50% water holding capacity through periodic additions of deionized water using a syringe. The soil used for incubation was taken from top 20 cm at Domboshava ICRAF research site in Zimbabwe. The soil, an Alfisol, had medium-grained sandy clay loam texture, 21% clay, 4% silt, 75% sand, pH 4.8 ($CaCl_2$), CEC 1.6 (% me), total exchangeable bases 0.9 (% me), organic carbon 0.61%, initial N 13 ppm ($NO_3$+$NH_4$), and initial resin extractable P of 9 ppm.

There were 10 treatments (9 prunings and 1 control) (Table 2.1). Each treatment was replicated three times in a randomized block design. The experiment was run for 8 weeks and a total of 240 plastic bags were used to allow eight samplings of each treatment. Sampling was done every week for 8 weeks. At the end of each week, mineralized N was determined by shaking 3 g of soil from each treatment with 30 ml 2 M KCl. The soil was extracted by shaking for one hour in 30 ml of 2 M KCl. The test tubes then were allowed to settle for 10 minutes, then filtered through No. 42 Whitman filter paper, and the aliquots were analyzed for $NH_4^+$ and $NO_3^-$ N.

Ammonia was analyzed by the modified colorometric method of Dorich and Nelson (1982) and nitrate by

colorometric method, cadmium reduction modification of Cataldo et al. (1975). Cumulative mineralized N was the total of ($NH_4$+$NO_3$) $\mu$g/g of soil extracted for sample.

## Statistical Analysis

An ANOVA was done using the SAS program (SAS Institute 1982) on initial quality chemical factors of MPTs and cumulative mineralized N for each week. Means were separated by the Duncan's multiple range procedure and declared different at $P < 0.05$. Correlation and regression analyses between cumulative mineralized N and initial pruning chemical indices were performed for each week of sampling.

# Results

## Chemical Properties of Prunings

The chemical composition of the various MPT prunings are summarized in Table 2.1. There were differences among MPT prunings on all the chemical quality factors measured. *Gliricidia sepium* (gliricidia) had lower % C compared to calliandra, cajanus, sesbania, and cajanus + sesbania; the rest of the species showed no differences. Both gliricidia and flemingia differed from the other species, and had the lowest N concentration of 1.8% of DM. The N of other species ranged from 2.5-3.1%. The highest N of 3.1% DM was found in cajanus and leucaena. The range of NDF-N was from 0.5%

Table 2.1 Chemical quality of prunings of different species (% dry matter basis).

| Treatments | %C | %N | %NDF-N | %LIGNIN | %SPPHENOL | TANNINS | C:N | L:N | P:N | (L+P):N | NDFN:N |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *A. angustissima* | 43 ab | 2.5 b | 1.9 a | 14.3 b | 12.2 b | 15.8 d | 17.6 | 5.8 | 5.0 | 10.7 | 0.8 |
| *G. sepium* | 38 b | 1.8 c | 0.9 d | 11.1 c | 2.3 d | 208.6 a | 20.7 | 6.1 | 1.3 | 7.3 | 0.5 |
| *F. macrophylla* | 44 ab | 1.8 c | 1.1 c | 19.3 a | 10.5 b | 102.6 b | 24.9 | 10.9 | 5.9 | 16.8 | 0.6 |
| *S. sesban* | 45 ab | 2.8 ab | 0.5 e | 6.7 d | 11.2 b | 16.4 d | 16.0 | 2.4 | 4.0 | 6.4 | 0.2 |
| *C. calothyrsus* | 48 a | 2.7 ab | 1.2 b | 11.4 c | 15.4 a | 53.3 c | 17.6 | 4.3 | 5.7 | 9.9 | 0.4 |
| *C. cajan* | 47 a | 3.1 a | 1.2 b | 14.0 b | 4.2 d | 88.9 b | 15.2 | 4.5 | 1.4 | 5.8 | 0.4 |
| *L. leucocephala* | 49 a | 3.1 a | 1.1 c | 12.0 c | 12.2 b | 49.7 c | 16.0 | 4.0 | 4.0 | 8.0 | 0.4 |
| *A. ang. + S. ses.* | 44 ab | 2.7 b | 1.2 b | 10.5 c | 11.7 b | 16.1 d | 16.3 | 3.9 | 4.3 | 8.2 | 0.4 |
| *C. caj. + S. ses.* | 46 a | 3.0 a | 0.9 d | 10.4 c | 7.7 c | 52.7 c | 15.3 | 3.5 | 2.6 | 6.0 | 0.3 |

Values followed by different letters in each column are significantly different from each other at $P < 0.05$ using Duncan's Multiple Range Test

% NDF-N = Percent nitrogen in cell wall (neutral detergent fraction)

% SPPHENOL = Percent soluble polyphenols

TANNINS = Insoluble proanthocynanidins read at absorbance of 550 nm/g NDF

(sesbania) to 1.9 (acacia). There were no differences in % NDF-N between gliricidia and cajanus + sesbania mixture and also among leucaena, cajanus, flemingia and calliandra (Table 2.1). *Acacia angustissima* had the highest % NDF-N among the rest of the species.

Lignin concentration was lowest in sesbania (6.7%), with a range of lignin concentration from 10.4-19.3% for the rest of the species. Flemingia had the most lignin at 19.3%. In terms of soluble polyphenols, gliricidia and cajanus had the lowest concentrations, with no differences between them. There also were no differences among acacia, flemingia, sesbania, leucaena, and the mixture of Aa + Ss. Insoluble proanthocyanidins (condensed tannin), read colorometrically at 550 nm/1 g of NDF, ranged from 15.8 to 208.6; *Gliricidia sepium* had the highest value of 208.6 followed by flemingia at 102.6, significantly different. There were no differences in insoluble proanthocyanidin concentrations among acacia, sesbania, acacia + sesbania mixture, and between leucaena, calliandra, and cajanus + sesbania mixture. Flemingia and cajanus did not differ in terms of condensed tannins.

## N Mineralization Patterns

The MPT prunings showed three main patterns of cumulative mineralized N over the 8-week incubation period. First was a pattern of rapid cumulative mineralization of N as shown by sesbania, gliricidia, cajanus, and the two

mixtures (Figure 2.1). Pattern two was shown by calliandra, leucaena, and acacia that had mineralization rates equal to or below that of the control (Figure 2.2). Mixing acacia and sesbania seems to have changed the pattern of acacia from that of N immobilization to net release (Figure 2.2). This response was not expressed in the cajanus+sesbania mixture, where the mixture response was not different from that of each species alone. A third pattern was shown by flemingia, where net N immobilization was below that of the control during most of the experimental period (Figure 2.2).

## Relationship Between Mineralized N and Chemical Properties

Cumulative mineralized N (CUMN) was positively correlated with % N and negatively correlated with C:N ratio but was not different ($P < 0.05$) at all 8 sampling dates. However, % NDF-N was negatively correlated with CUMN at weeks 1, 2, 3, 4, and 8 (Table 2.2). CUMN was negatively correlated with % lignin at all sampling dates. There was no correlation between CUMN and % soluble polyphenols. Condensed tannins also showed no correlation with CUMN (Table 2.2).

CUMN was negatively correlated with the lignin:N, soluble polyphenols:N, (lignin + polyphenol):N and NDF-N:N ratios at all sampling dates (Table 2.2). CUMN was correlated with lignin:N only at week one (Table 2.2), whereas with polyphenol:N ratio, it correlated with CUMN

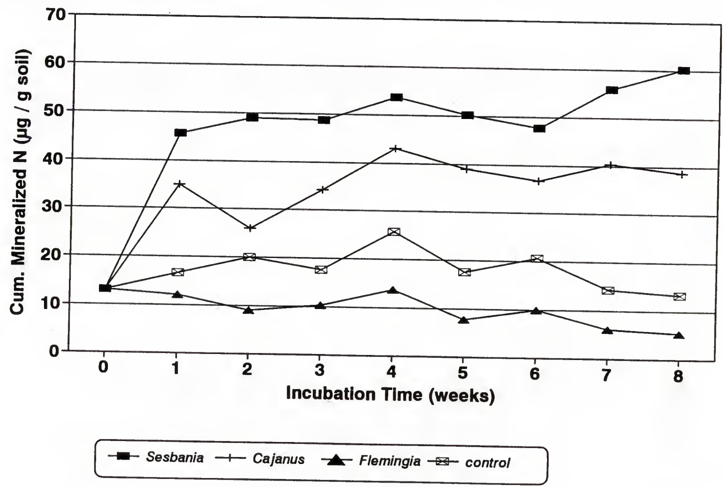


Figure 2.1 Cumulative mineralized nitrogen as affected by MPT pruning quality.

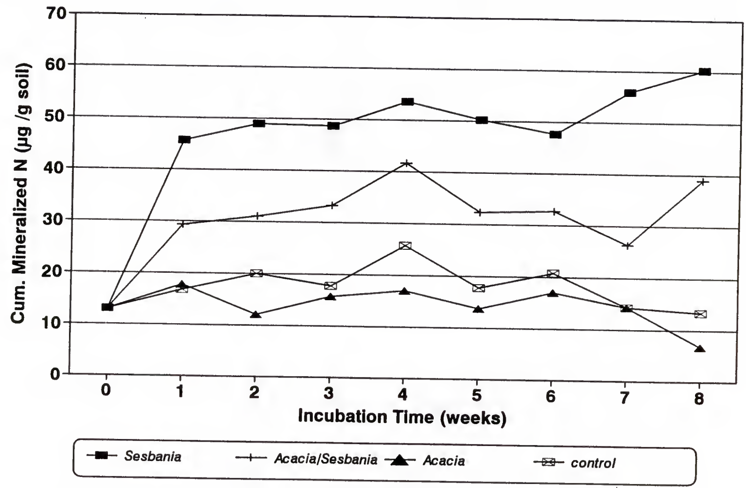


Figure 2.2 Cumulative mineralized nitrogen as affected by MPT pruning quality.

Table 2.2 Correlation coefficients relating cumulative mineralized N to initial chemical properties of prunings over time.

| TIME (wks) | NDF-N | LIGNIN | SPPHENOL | TANNINS | L:N | P:N | L+P:N | NDFN:N |
|---|---|---|---|---|---|---|---|---|
| 1 | -0.64 * | -0.78 ** | -0.39 | -0.01 | -0.68 * | -0.59 | -0.78 ** | -0.73 * |
| 2 | -0.70 * | -0.75 * | -0.53 | -0.23 | -0.51 | -0.64 | -0.68 * | -0.61 |
| 3 | -0.61 | -0.70 * | -0.44 | -0.06 | -0.59 | -0.59 | -0.72 * | -0.68 * |
| 4 | -0.66 * | -0.73 * | -0.54 | 0.10 | -0.61 | -0.71 * | -0.79 ** | -0.71 * |
| 5 | -0.65 * | -0.75 * | -0.53 | 0.07 | -0.64 | -0.71 * | -0.81 ** | -0.72 * |
| 6 | -0.62 | -0.73 * | -0.55 | 0.07 | -0.62 | -0.72 * | -0.80 ** | -0.68 * |
| 7 | -0.63 | -0.68 * | -0.57 | 0.19 | -0.54 | -0.71 * | -0.74 * | -0.62 |
| 8 | -0.68 * | -0.71 * | -0.56 | 0.33 | -0.49 | -0.67 * | -0.68 * | -0.59 |

Values followed by * or ** are significant at $P < 0.05$ and $P < 0.01$ respectively

from weeks 4 to 8. CUMN and NDF-N:N ratio were negatively correlated at weeks 2, 3, 4, and 5 (Table 2.2). (Lignin + polyphenol):N and CUMN were negatively correlated at all sampling dates. When CUMN was regressed against the main litter quality parameters (Table 2.1) at each sampling date, % lignin and % soluble polyphenols accounted for more than 80% of the variation in CUMN in most weeks (Table 2.3). However, at week 6, % C, % N, and condensed tannin become significant terms in the regression model in addition to % lignin and % soluble polyphenols.

Various models were tried to fit the relationship between CUMN and various ratios (Figures 2.3 and 2.4). These relationships were best described by a curvilinear model for (lignin + polyphenol):N ratio, and a linear model for polyphenol:N ratio.

## Discussion

Litter decomposition and N mineralization are determined by climate and litter quality (Swift et al. 1979). Most studies have attempted to determine what aspects of litter quality are responsible for differences in N release patterns and how important quality parameters can be summarized into a simple measure or index for predicting N release (Fox et al. 1990).

In most studies, initial % N or C:N ratio of the prunings was found to be the best predictor of N release

Table 2.3 Multiple regression equations for cumulative mineralized N vs. chemical properties at eight sampling dates.

| TIME (wks) | EQUATION (n=9) | $R^2$ |
|---|---|---|
| 1 | y = 58.21 - 2.49 L | 0.61 |
| 2 | y = 87.78 - 3.40 L - 2.02 P | 0.87 |
| 3 | y = 92.29 - 2.34 L - 2.95 P | 0.84 |
| 4 | y = 92.69 - 3.23 L - 2.05 P | 0.85 |
| 5 | y = 85.86 - 3.21 L - 1.92 P | 0.86 |
| 6 | y = 73.52 + 2.80 C - 26.33 N - 3.60 L - 4.58 P - 0.21 T | 0.98 |
| 7 | y = 91.47 - 3.39 L - 2.35 P | 0.82 |
| 8 | y = 11.407 - 4.46 L - 2.93 P | 0.85 |

Y = cumulative mineralized Nitrogen for each sampling date

L = lignin

P = soluble polyphenols

C = percent carbon

N = percent nitrogen

T = condensed tannins

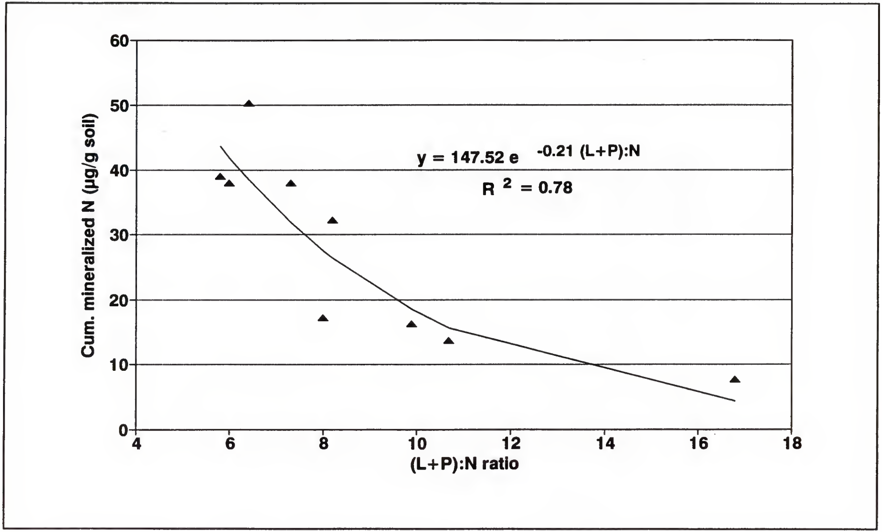


Figure 2.3 The relationship between cumulative mineralized nitrogen and (lignin+polyphenol):N ratio of leaves.

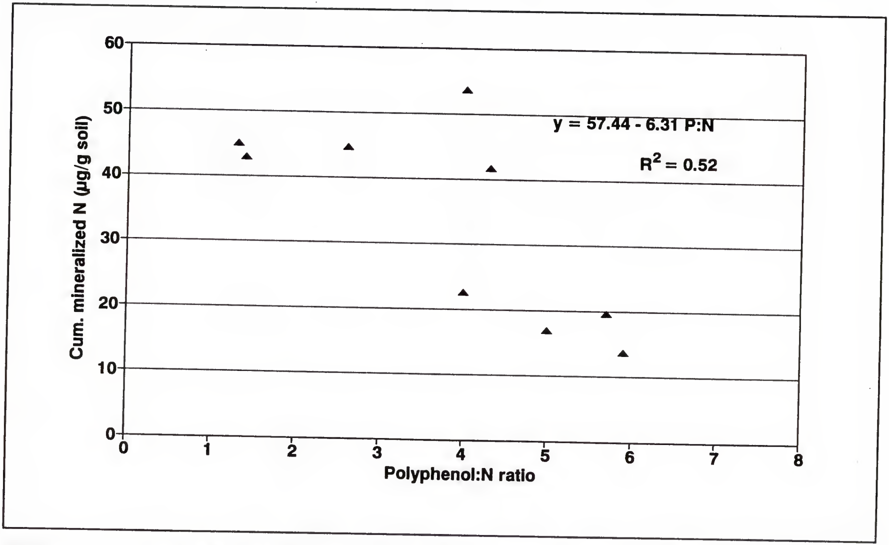


Figure 2.4 The relationship between cumulative mineralized nitrogen and soluble polyphenols:N ratio of leaves.

(Thorup-Kristensen 1994). The critical threshold for N release was found to be 1.73%, and a C:N ratio of 20 would allow immediate release of N (Frankenberger and Abdelmagid 1985). However, in this study, C:N ratio and % N were not found to be correlated with N release. Since most of the MPT species had greater than 1.73% N and C:N ratios < 20, it was expected they would release N immediately. This was not the case. In fact, acacia, leucaena, calliandra, and flemingia, with C:N ratio < 20, immobilized N most of the time (Figure 2.2). Our results agree with those of Palm and Sanchez (1991) and Oglesby and Fownes (1992), who found % N and C:N ratio to be poor predictors of N release. However, Tian et al. (1992b) and Sandhu et al. (1990) found that % N and C:N ratio were good predictors of N release. In this study, we found that % NDF-N was correlated with N release. Few studies have separated total N into labile N and NDF-N. It appears that for MPT prunings high in lignin, total % N is not a very useful predictor of N release. Instead, NDF-N is more appropriate because it separates N into a labile pool, which is easily degradable, and NDF-N which is resistant to microbial degradation.

Polyphenols are water soluble compounds that are reported to be capable of binding plant proteins (Haslam 1989) and reducing N release from decomposing litter (Palm and Sanchez 1991, Oglesby and Fownes 1992, and Tian et al. 1992a). Our results do not corroborate this relationship but

agree with the results of Fox et al. (1990), Becker et al. (1994) and Handayanto et al. (1994) who found no relationship between CUMN and % soluble polyphenols. It is worth pointing out that the type of materials used and the method of polyphenol extraction were not the same in all studies. Palm and Sanchez (1991) and Oglesby and Fownes (1992) used green leaves and the Denis-Folin method (a colorometric technique) to measure polyphenols, while we used sun-dried prunings (which contain less polyphenols than fresh prunings) and the ytterbium acetate gravimetric method.

Lignin is known to be highly resistant to microbial decomposition (Melillo et al. 1982). It may also slow N mineralization due to lignin-bound N. Our results confirmed this since lignin was highly correlated with CUMN throughout the experimental period. Similar results have been reported by Stump and Binkley (1993), Tian et al. (1992a), Becker et al. (1994) and Oglesby and Fownes (1992). However, Palm and Sanchez (1991), Fox et al. (1990) and Melillo et al. (1982) found no effect of lignin on N release. But these workers used species which showed a narrow range of % lignin concentration, whereas the species used in our study had a wider range of % lignin (Table 2.1). As reported by Taylor et al. (1989), when a species has a low concentration of lignin, then lignin has no effect the pattern on N release.

The ratios of chemical constituents reflect the interaction between variables and offer potentially reliable indices for prediction of N release (Taylor et al. 1989). Melillo et al. (1982), Stump and Binkley (1993), and Cotnifo et al. (1994) found L:N ratio to be a good predictor of N release from temperate deciduous forest litter. Our results with tropical leguminous litter found this ratio to be correlated with CUMN during the first week of sampling only, but not during the remaining 7 weeks. This confirms the results of Oglesby and Fownes (1992), Palm and Sanchez (1991) and Fox et al. (1990). However, these workers found polyphenol:N ratio to be a good predictor of N release. Our results also corroborate the use of polyphenol:N ratio as a predictor of N release. In addition, NDF-N:N ratio was also negatively correlated with N release. There are no reports in the literature about the use of this ratio. This ratio separates total N into labile N and unavailable N which have different capacities to undergo microbial degradation. Therefore the polyphenol:N ratio could be a better predictor; it needs further investigation across a wider range of species. The ratio which was consistently correlated with CUMN at all sampling times was (lignin + polyphenol):N ratio. Similar results have been reported in earlier studies as well (Fox et al. 1990; Handayanto et al. 1994; Becker et al. 1994). Constantinide and Fownes (1994),

Thomas and Asakawa (1993) and Kachaka et al. (1993) also found this ratio to be the best predictor of N release.

It appears from the correlation of chemical quality factors and their ratios with CUMN that lignin, polyphenols, NDF-N, and total N are the main factors regulating N release. Table 2.4 summarizes the relationships between chemical quality parameters and N release patterns of MPT species. Multiple regression analysis also confirms the importance of lignin and polyphenols in regulating N release patterns.

Among the species in this study, sesbania, gliricidia, and cajanus had rapid N release. Some of these species had either low % lignin or soluble polyphenols, low polyphenol:N or (lignin + polyphenol):N, and NDF-N:N ratio. Leucaena, calliandra, and acacia had a pattern of initial release and N immobilization; these species had high % NDF-N, lignin, and soluble polyphenols resulting in high (lignin + polyphenol):N ratios. Flemingia, which immobilized N most of the time, had the highest % lignin and (lignin + polyphenol):N ratio, and the lowest % N, with 61% of total N found in the NDF fraction. It was surprising to find that leucaena immobilized N although most other studies have reported leucaena to release N rapidly. However, the results of Palm and Sanchez (1991) and Fox et al. (1990) agree with our result, which can be explained on the basis of the chemical composition of leucaena. Tian et al. (1992a) and Oglesby and

Table 2.4 Relationships between MPT species' chemical quality parameters and N release patterns.

| *category of mulch* | *chemical quality parameters* | *MPT species* | *N release pattern* |
|---|---|---|---|
| High quality | high N (> 2.5%)<br>low NDF-N (< 1.0%)<br>low soluble poyphenols (< 5%)<br>low lignin (< 10%) | Sesbania sesban<br>Gliricidia sepium<br>Cajanus cajan | rapid release<br>> 20% N released in 8 weeks after application |
| Medium quality | high N (> 2.5%)<br>medium NDF-N (1-1.5%)<br>high soluble polyphenols (> 10%)<br>high lignin (10-15%) | Calliandra calothyrsus<br>Leucaena leucocephala<br>Aa + Ss mixture | slow release<br>> 2% released in 8 weeks after application |
| Low quality | low N (< 2.0%)<br>high NDF-N (> 1.5%)<br>high soluble polyphenols (>10%)<br>very high lignin (>15%) | Flemingia macrophylla<br>Acacia angustissima | N immobilization<br>> 2.4% N immobilized 8 weeks after application |

Fownes (1992) found sesbania and gliricidia to release N rapidly. This also agreed with our results. Mixing acacia and sesbania changed the pattern of N release from immobilization (acacia alone) to rapid release (mixture). Becker et al. (1994) also found a mixture of rice straw + sesbania to release N more rapidly than rice straw alone, which immobilized N.

The diverse patterns of N release observed in this study can be explained on the basis of how lignin and polyphenols affect N release from prunings. Polyphenols can form complex structures with hydrogen or covalent bonding with amino acids, making the material resistant to decomposition. In addition, phenolics can be readily oxidized to quinone either by autoxidation or enzymes (Palm and Sanchez 1991). Quinones react with amino acids to form stable polymers which are precursors of fulvic and humic acids found in soil organic matter (Stevenson 1982). A third mechanism could be that phenolic acids from lignin degradation and microbial degradation of polyphenols react with $NH_4^+$ or $NO_2$ making these substrates less available to the nitrifying bacteria and hence less $NO_3^-$ being formed (Kholdebaria and Oertli 1994). Lignin is capable of reducing the availability of both carbohydrates and protein by complexing them in much the same way as polyphenols (Swain 1979). It is also likely that lignin can be degraded to simpler polyphenol compounds which increase the amount of

insoluble protein complexes present in the system. That could perhaps be the reason that lignin + polyphenol:N ratio was a good predictor of N release. However, materials like sesbania and gliricidia, which are low in lignin or soluble polyphenols, have their N in the labile pool which is easily leached or mineralized. It would be difficult to know which mechanism was at work in polyphenol- and lignin-rich materials since the polyphenol N complexes may end up in the same lignin fraction which is acid insoluble in many laboratory analyses. Therefore, what is estimated as lignin in the analyses could be other polyphenolic compounds. This area needs further research to determine which mechanisms are responsible for low N release.

The results of the study have shown that the prunings of sesbania, gliricidia, cajanus, and mixtures of cajanus + sesbania and acacia + sesbania could release N in the short term to meet current N demand of the companion crop in alley cropping. However, prunings high in lignin and polyphenols such as calliandra, acacia, and flemingia would immobilize N and may release it later. The implication of this N release pattern would be interesting in terms of their effect on soil organic matter pools that are built up from continuous application of such materials. Mixing of slow release materials with fast N release materials as shown with acacia and sesbania have a potential to achieve synchrony between N release and N demand by a crop. This needs further testing.

The (lignin + polyphenol):N ratio could be a good index for screening various MPT species for their potential as sources of N to annual crops. However, before we advocate wide use of this index, there is a need to standardize the analyses of polyphenols and take into account the effects of species, age of prunings, and drying methods on polyphenol concentration. It must be remembered that results of this study were obtained in a controlled experiment with optimal temperature and moisture conditions. Given the wide fluctuations of these factors under field conditions, these results need to be replicated under a wide variety of field conditions.

CHAPTER 3

# MANAGEMENT OF MPT PRUNINGS AS A NITROGEN SOURCE TO MAIZE: PART 1. EFFECT OF THE METHOD OF PRUNINGS APPLICATION ON NITROGEN RECOVERY BY MAIZE

## Introduction

Although prunings from leguminous trees can supply nitrogen for crop production, N-utilization efficiencies (NUE) of the prunings are reported to be low compared to those of inorganic N fertilizers (Xu et al. 1993, and Kang et al. 1981). Nitrogen contribution from prunings of leucaena applied at 5 t $ha^{-1}$ to maize on alfisols was reported to be in the range of 10-40 kg N $ha^{-1}$ in the subhumid tropics of Nigeria (Mulongoy and van der Meersch 1988) and the semiarid tropics of Australia (Xu et al. 1993). This represents less than 30% of the N contained in the prunings applied. The low NUE of the prunings is probably due to lack of synchronization between N demand of the crop and N release from prunings, or N losses through volatilization, immobilization and leaching.

The lack of synchrony (or asynchrony) may occur when N is released at a rate exceeding the uptake or slower than crop N needs. A combination of these processes may occur at specific times during the crop's growing cycle. Very few

studies have been done to document these processes. Based on studies conducted in the humid tropics, Yamoah et al. (1986) reported that N release exceeded crop's demand for the first 65 days after sowing the crop, but thereafter it was less. Only two reports on this aspect are available from the semiarid zones, those of Xu et al. (1993) and Jama (1993). All these studies, both in the humid or the semiarid tropics, were done with one or two tree species, e.g., leucaena (Xu et al. 1993) or leucaena and cassia (Jama 1993). There is a need to conduct such studies with MPT species with varying pruning quality under different environmental and management conditions. Most of the NUE values to date have been based on maize grain yield and total N uptake data collected at the time of maize harvest. Hence one cannot determine whether it was N or other factors that were limiting maize growth, and if so, to what extent and at what growth stages. This study was undertaken to address such issues.

Various management factors such as pruning quality, method and time of pruning application need to be considered to improve N recovery (NIR) rates of MPT prunings as a source of N to crops. Incorporation of prunings may improve NIR due to rapid decomposition and lower N losses due to volatilization. Incorporating 10 t $ha^{-1}$ of leucaena and gliricidia gave 65% and 25% more grain yield than surface application of the same quantity of prunings in an Alfisol

in subhumid Nigeria (Kang and Duguma 1985). Reed et al. (1985b) and Kang et al. (1981) found that incorporating leucaena prunings gave higher maize yield and N uptake than surface application. However, mulching has been reported to have many positive effects in tropical agriculture including slow and continuous nutrient release, moisture conservation, reduced soil temperature fluctuations (Budelman 1988, 1989) and reduced weed seed germination (Tomar et al. 1992). When considering agroforestry technologies for crop production in the semiarid regions, the effects of mulching with MPT prunings of different quality need to be studied.

The quality and quantity of prunings can also improve NIR of prunings. Leucaena prunings with narrow C:N ratios, low lignin, and which decompose rapidly were found to meet companion crops' needs efficiently. However, prunings of low quality such as flemingia or cassia which decompose slowly (see Chapter 2) can reduce N losses and can improve residual effects (Yamoah et al. 1986). In the case of lower-quality organic materials, which decompose more slowly, their residual effect on crops may be greater than their immediate effect. Continuous application of low quality prunings may lead to build up passive soil organic pools which maintain soil fertility in the long term. In order to utilize pruning N to the fullest extent, a better understanding of the pattern of N availability and accumulation in maize following pruning application is needed.

This experiment was conducted under field conditions in order to determine the following:

1. The effect of pruning placement (surface vs incorporation) on rates of decomposition and N release of five MPT species.
2. The effect of pruning quality on decomposition and N release rate.
3. The extent of synchronization of pruning N release and maize N uptake.

## Materials and Methods

### Site

The experiment was conducted at the field station of the International Centre for Research in Agroforestry (ICRAF) located at Domboshava, Zimbabwe (17° 35′ S latitude, 3° 14′ E longitude), at an altitude of 1475 m. The mean annual temperature is 23°C and annual rainfall is 750 mm. The rainfall pattern is unimodal starting in November and ending in April. The total rainfall received during the experimental period was 607 mm (Table 3.1). The experiment was conducted from November 1993 to April 1994. Prior to the opening of the station in 1991, the site was under a grass fallow for a number of years. The field was cropped to maize in the 1992/93 season with no inorganic fertilizer applied. The main soil type at the station is an alfisol (ustalfs in the USDA classification; lixisol by FAO classification) with a sandy loam texture. The main physical and chemical

Table 3.1 Total rainfall received during the growing season from November 1993 to April 1994.

| *Month* | *rainfall (mm)* |
|---|---|
| November | 103.3 |
| December | 67.3 |
| January | 218.5 |
| February | 86.9 |
| March | 119.9 |
| April | 10.6 |
| Total | 607.7 |

Table 3.2 Soil characteristics at beginning of the experiment.

| | |
|---|---|
| Texture | medium sandy clay loam |
| clay % | 21.0 |
| silt % | 4.0 |
| sand % | 75.0 |
| pH ($CaCl_2$) | 4.8 |
| total exchange bases (me%) | 0.9 |
| CEC (me%) | 1.6 |
| organic carbon % | 0.61 |
| resin extractable P | 10.0 ppm |
| available N after incubation | 29.0 ppm |

properties of the 0-20 cm soil layer at the beginning of the experiment are shown in Table 3.2.

Experimental Design and Treatments

The treatments were a combination of two factors: 1) method of prunings application (surface application vs. incorporation into the top 0-20 cm), and 2) MPT species, in which five leguminous shrubs considered appropriate for agroforestry technologies in Zimbabwe were used. The species were *Acacia angustissima* (acacia), *Calliandra calothyrsus* (calliandra), *Cajanus cajan* (cajanus), and *Leucaena leucocephala* (leucaena). The fifth "species" was litter collected from a secondary forest of *Brachystegia spiciformis* Benth. (miombo). Applying miombo litter to crops is a practice commonly used by local farmers to maintain soil fertility in their fields. A control plot was included where no prunings were applied, but soil disturbance was applied. Thus, there were 11 treatments.

A randomized complete block design with three replications was used for the trial, with gross plots 5.4 m wide and 6.6 m long, and six rows of maize hybrid cultivar R215 planted at 90 cm between rows and 30 cm within rows. Two seeds were planted per hole and thinned to one plant per station to give a maize population of 37,000 plants $ha^{-1}$. All plots received a basal fertilizer application of 60 kg P $ha^{-1}$ as single superphosphate and 40 kg K $ha^{-1}$ as muriate of

potash. Plots were manually weeded using a hand hoe when necessary.

For determination of maize dry matter yield and N uptake, six maize plants were randomly harvested (cut at soil level without harvesting roots) from the two rows at 4, 6, 9, and 12 weeks after planting (WAP), and final harvest. At final harvest, maize grain and stover yield data were obtained from a net plot of two center rows (6.0 m long x 1.8 m wide). Maize yield was determined at 12.5% moisture. At each sampling date, subsamples were oven dried at 65° C for 48 hr for dry matter determination. Then the samples were ground to pass through 2-mm mesh for N analysis.

Maize N uptake was calculated by multiplying the maize N concentration by corresponding dry weights at each sampling date. N release from the prunings was calculated by subtracting residual N in the prunings at each sampling date from total N applied at the beginning of the experiment. NIR was calculated according to the following formula:

$$NIR = \frac{N\ uptake\ treatment - N\ uptake\ control}{N\ initially\ applied} \times 100\%$$

## Prunings Management

The prunings of the four species were cut from fodder banks grown at Domboshava at the end of the rainy season in April 1993. They were sun dried for three days on concrete

floors and stored in jute bags until the beginning of the experiment. Subsamples of prunings were oven dried at 65° C for 48 hr to determine the dry matter content; results of chemical analyses are expressed in % DM. The prunings were analyzed for initial N, lignin, soluble polyphenols, and protein binding capacity of the polyphenols in the prunings. The initial chemical composition is shown in Table 3.3 . Nitrogen was analyzed by standard micro Kjeldahl method, lignin by the acid detergent method (Goering and van Soest 1970), and soluble polyphenols by Folin-Denis method (Anderson and Ingram 1990) with tannic acid as a standard. The protein binding capacity was determined by the bovine serum albumin (BSA) method (Dawra et al. 1988), by applying pruning extracts to chromatography paper and reacting with BSA. Unbound BSA was washed off and bound protein polyphenol complex stained with Porceou S. The protein was eluted and absorbance recorded at 525 nm which was converted to protein units ($\mu$g BSA mg$^{-1}$ of plant extract) by a calibration curve (Dawra et al. 1988). Prunings were applied at 5 t ha$^{-1}$ at planting of the maize crop. Incorporation of the prunings was achieved by applying mulch on the surface and mixing it with the 0-20 cm layer of soil using hand hoes.

Pruning Decomposition and N Release

Decomposition and N release from the prunings were studied by using litter bags measuring 20 cm x 20 cm with a

Table 3.3 Chemical properties of the prunings used in this study.

| MPT SPECIES | CHEMICAL COMPOSITION | | | |
|---|---|---|---|---|
| | % N | % lignin | % soluble polyphenols | protein binding capacity * |
| *Acacia angustissima* | 3.18 (143)** | 11.70 | 3.32 | 13.26 |
| *Calliandra calothyrsus* | 2.59 (117) | 18.88 | 3.47 | 17.02 |
| *Cajanus cajan* | 3.95 (178) | 14.37 | 1.69 | 5.03 |
| *Leucaena leucocephala* | 2.77 (125) | 8.13 | 3.40 | 3.67 |
| *Brachystegia speciformis* (miombo litter) | 1.07 (48) | 28.27 | 2.67 | 3.41 |

* µg bovine serum albumin (BSA) per mg plant extract (PE)

** Figures in parentheses are amount of N (kg/ha) in prunings applied at planting.

1-mm mesh size. The litter bags, with 50 g of sun-dried prunings each, were either placed on the surface or buried in the top 0-25 cm of soil in a vertical position depending on the treatment. This was done in the field with the maize crop of 37,000 plants $ha^{-1}$ during the growing season. Six sampling of litter bags were done at 2, 4, 6, 9, and 12 WAP, and at final harvest to determine residual dry matter of prunings and N in the litter bag. At each sampling, prunings remaining in the litter bags were cleaned with soft brushes, dried at 65° C for 48 hr to determine residual dry matter, and ground to pass through a 1-mm mesh for N analysis.

## Data Analysis

The equation $Y_t = Y_0\, e^{-kt}$, where $Y_t$ = the remaining fraction of initial dry weight or nitrogen at time ($t$) in weeks, was used to calculate decomposition constant ($k_D$) and N release constant ($k_N$) (Weider and Lang 1982). The constant $k$ refers to the rate of weekly decomposition, or N release, expressed as a percentage. The decomposition and N release constants were subjected to ANOVA using SAS. A correlation analysis was performed on initial pruning chemical quality factors with decomposition constant and N release constant. The other data collected (dry matter accumulation, N uptake, N release, NIR for each sampling date, and grain yield) were also subjected to ANOVA using SAS. The model was a two-way ANOVA classification with method of pruning application and

MPT species as the main effects. An interaction term was included in the ANOVA model. Treatment means were declared significant at $P < 0.05$ using Least Significance Difference of mean separation.

## Results

In terms of rainfall, the 1993/1994 season was average with a total rainfall 607 mm recieved during November 1993 to April 1994. (Table 3.1). Although this total was 143 mm less than the long term average of 750 mm, it was evenly distributed during the growing season.

The prunings used in this study showed quite a variation in chemical quality (Table 3.3). Calliandra, leucaena, and acacia had quite high % polyphenols, with calliandra and acacia showing the highest protein binding capacity. Lignin concentration ranged from 8 to 28% with acacia, cajanus, and calliandra having their lignin range between 11-18%. Miombo litter had the highest % lignin (28%). The highest amount of N supplied by the species was in the order cajanus > acacia > leucaena > callianra > miombo litter; miombo litter gave 48 kg N $ha^{-1}$ (Table 3.3).

### Growth and Above-Ground Dry Matter Accumulation of Maize

There was an effect of method of pruning application on % maize emergence. Seven days after planting, all mulched plots had 86% emergence *vs.* 45% in pruning-incorporated

treatments. The incorporated treatments took 14 days after planting to reach 80% emergence. This difference in % emergence can explain the high variation in maize DM accumulation observed at 4 and 6 WAP sampling dates. There was an interaction of method of pruning application and MPT species on DM accumulated at all sampling dates (Table 3.4).

Four weeks after planting

At 4 WAP, prunings applied on the surface as mulch produced more above-ground maize biomass than incorporated, except for calindra and cajanus. When prunings were applied as mulch, maize biomass was in the order acacia > calliandra > miombo litter. Cajanus was equal to leucaena in maize DM yield. With incorporated prunings, there were no differences among MPT species except that miombo litter yielded less maize DM than leucaena. Across species, method of pruning application had an effect on maize DM accumulation. Miombo litter yielded more maize DM when prunings were surface-applied than incorporated. Leucaena prunings application resulted in more maize DM when incorporated than when surface applied. However, with cajanus, application method had no effect on maize dry matter accumulation.

Six weeks after planting

Application method had significant effect on maize dry matter accumulation at 6 WAP. In the case of acacia, calliandra, and cajanus, surface-applied prunings resulted

Table 3.4 Maize dry matter yield (kg $ha^{-1}$) as affected by method of placement and MPT species.

| SPECIES | TIME AFTER PLANTING (weeks) 4 | | 6 | | 9 | | 12 | |
|---|---|---|---|---|---|---|---|---|
| | S | I | S | I | S | I | S | I |
| *A. angustissima* | 125.6 a | 61.0 ab | 464.0 a | 333.7 b | 1203.0 c | 2627.0 a | 3995.3 c | 5197.7 c |
| *C. calothyrsus* | 83.6 b | 65.0 ab | 358.7 c | 331.7 b | 2202.0 a | 2001.3 b | 6400.0 a | 7277.0 a |
| *C. cajan* | 65.0 c | 74.3 ab | 413.0 b | 313.0 b | 2216.7 a | 1952.7 b | 4486.7 b | 6290.0 b |
| *L. leucocephala* | 51.7 c | 76.0 a | 345.0 c | 384.3 a | 1744.0 b | 1363.3 c | 3660.0 c | 6364.0 b |
| *B. speciformis* | 81 b | 60.3 b | 347.7 c | 329.7 b | 1150.7 c | 1554.3 c | 2175.7 d | 3928.3 d |
| LSD $P < 0.05$ | 15.5 | | 34.3 | | 276.2 | | 271.2 | |

Means within a column followed by the same letter are not different ($P < 0.05$) using the LSD mean separation procedure.

S = surface application
I = incorporation

in more maize DM matter than when incorporated. With leucaena, incorporation of prunings was better than surface application. Application method had no effect on maize DM yield for miombo litter at 6 WAP. While considering surface application of prunings, acacia gave the highest maize DM yield followed by cajanus, with differences between them. The effect of calliandra, leucaena and miombo litter mulches were similar, but different from those of acacia and cajanus. When incorporation of prunings was considered, only leucaena was different from the other MPT species in terms of maize dry matter accumulation.

Nine weeks after planting

Method of pruning application had an effect on maize DM accumulation at 9 WAP in the case of some MPT species. With acacia, leucaena, and miombo litter, incorporation of their prunings produced more maize DM than surface application. However, for calliandra and cajanus, the method of application of their mulch had no effect on maize DM yield. Considering surface application of mulch across all species, calliandra and cajanus resulted in the highest maize DM yield with no difference between them, followed by leucaena which was lower than the former two. Acacia and miombo litter application resulted in the same amount of biomass showing no differences between them. However, considering pruning incorporation across the species, acacia resulted in the highest maize biomass yield, followed by cajanus and

calliandra which resulted in similar effects. The least amounts of maize biomass were produced with leucaena and miombo litter (Table 3.4).

Twelve weeks after planting

At 12 WAP, incorporation as method of pruning application produced significantly more maize dry matter than surface application for all species (Table 3.4). However, when prunings were applied as mulch, there were differences among species on maize DM production: calliandra > cajanus > acacia = leucaena. Miombo litter application produced the least amount of maize biomass. Considering pruning incorporation across the species, there was an effect on maize DM accumulation: calliandra > cajanus = leucaena > acacia > miombo litter.

Maize Grain Yield

There was a significant interaction of method of pruning application and MPT species on maize grain yield (Figure 3.1). Among the species, application method had a significant effect on grain yield. For acacia, leucaena and cajanus, incorporation of prunings gave higher maize grain yield than surface application. However for calliandra and miombo litter, method of application had no effect on grain yield. Considering the effect of species within the surface application method, species ranked as calliandra = cajanus = leucaena > acacia > miombo = control.

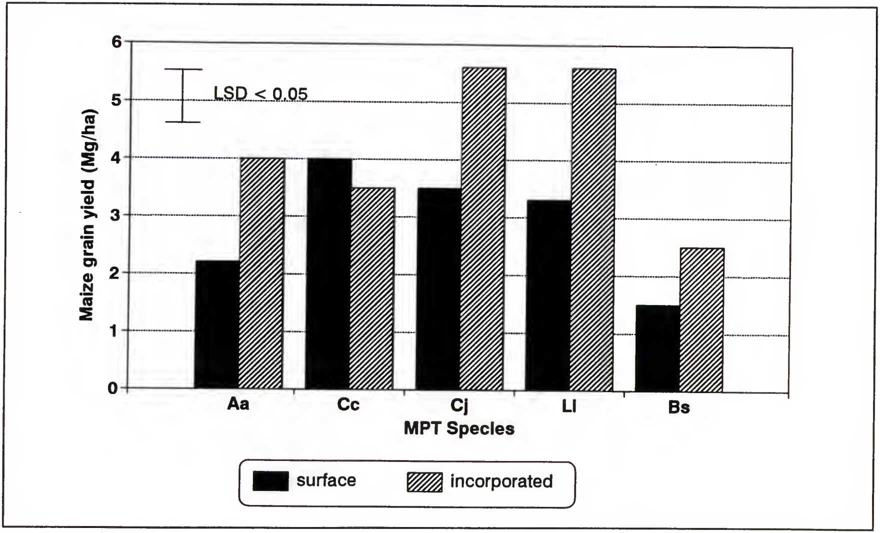


Figure 3.1 Maize grain yield (Mg ha$^{-1}$) as affected by method of pruning application and MPT species.

When prunings were incorporated, cajanus and leucaena gave the highest maize grain yield of 5.6 Mg $ha^{-1}$ which was five times that obtained from the control treatment of 1.1 Mg $ha^{-1}$. There was no difference between acacia and calliandra in terms of grain yield, although yields of these two species differed from leucaena and cajanus. Miombo litter gave the lowest maize grain yield of 2.5 Mg $ha^{-1}$ which was different from the rest of the species and the control treatment.

## Decomposition and Nitrogen Release Constants

The decomposition of the MPT prunings was affected by a method of application x MPT species interaction (Figure 3.2). For acacia, cajanus, leucaena and miombo litter, incorporation of prunings gave higher decomposition rates than surface application of prunings. However, for calliandra, method of application had no effect. Within methods of application, there was a species effect. When prunings were applied on the surface as mulch, decomposition rates for cajanus > calliandra = leucaena = miombo > acacia. However, when incorporated, rates for cajanus = leucaena > acacia = calliandra.

There was an interaction of method of pruning application and MPT species on N-release constants of MPT species. Incorporation of prunings gave higher N-release constants for all species (Figure 3.3). When prunings were

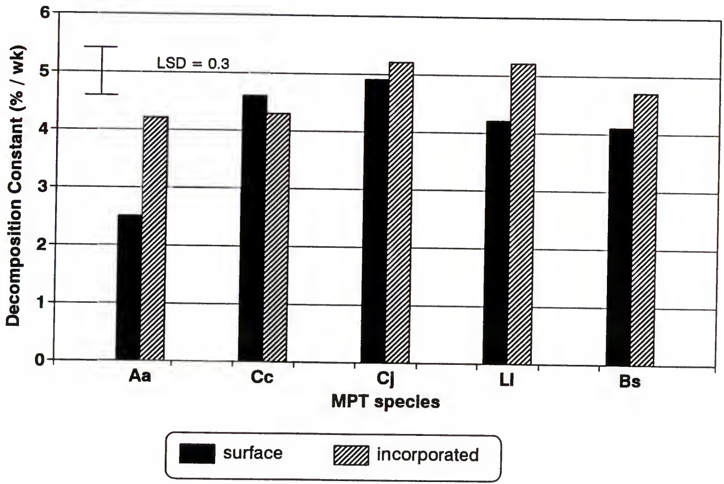


Figure 3.2 Decomposition constant as affected by method of pruning application and MPT species.

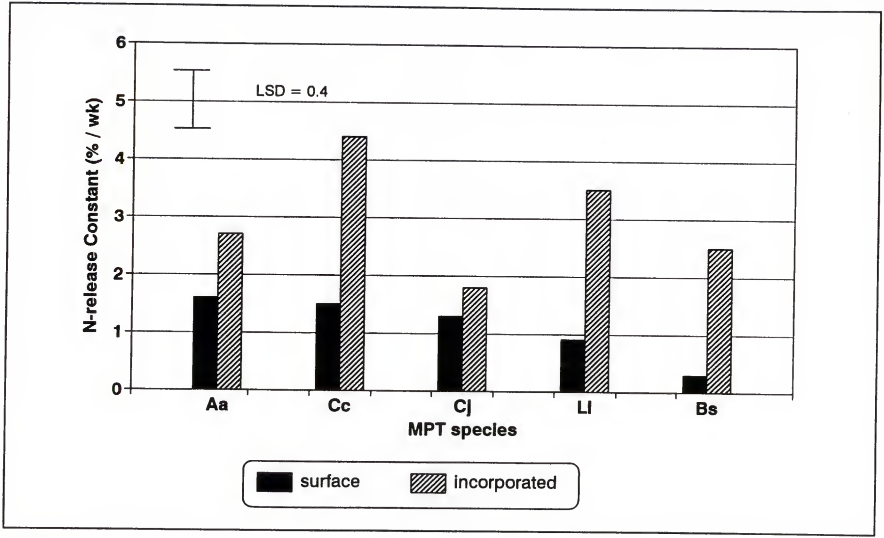


Figure 3.3 Nitrogen release constant as affected by method of pruning application and MPT species.

applied as mulch, N release for acacia = calliandra = cajanus > leucaena > miombo. However, when incorporated, N release for calliandra > leucaena = acacia = miombo. The decomposition rate of prunings was negatively correlated with % polyphenol ($r=0.51$) and protein binding capacity of the polyphenols ($r=0.39$). The N release constants were negatively correlated with % polyphenols ($r=0.39$; $P<0.05$).

Pattern of Cumulative N Release

There was a significant interaction between the method of pruning application and MPT species ($P<0.05$) on cumulative N released (Table 3.5). At 2 WAP, incorporation of cajanus prunings resulted in greater release of N than surface application. For calliandra, surface application released more N than incorporation. For acacia, leucaena and miombo litter, method of application had no effect on N released at 2 WAP.

Within methods of pruning application, MPT species affected cumulative N released. Cajanus, acacia, and calliandra released higher amounts of N when prunings were applied on the surface as mulch, but there was no difference among these species. Leucaena mulch released the least amount of N when surface-applied. Miombo litter immobilized N. Cajanus released the highest amount of N when prunings were incorporated. There was no difference between the amount of N released by leucaena and acacia when prunings

Table 3.5 Nitrogen released (kg $ha^{-1}$) as affected by method of placement and MPT species.

| SPECIES | TIME AFTER PLANTING (weeks) 2 | | 4 | | 6 | | 9 | | 12 | | HARVEST | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | S | I | S | I | S | I | S | I | S | I | S | I |
| *A. angustissima* | 32.3 a | 30.0 b | 57.7 a | 74.0 a | 51.0 a | 67.7 b | 56.3 a | 71.0 b | 49.0 b | 80.3 b | 64.3 b | 67.7 b |
| *C. calothyrsus* | 34.4 a | 10.5 c | 44.3 b | 14.9 c | 36.0 b | 26.7 c | 27.0 b | 34.7 d | 39.0 c | 41.0 d | 26.9 c | 64.3 b |
| *C. cajan* | 36.7 a | 67.7 a | 58.7 a | 76.0 a | 50.7 a | 81.3 a | 55.0 a | 91.3 a | 56.3 a | 87.3 a | 82.3 a | 97.7 a |
| *L. leucocephala* | 15.0 b | 24.3 b | 21.7 c | 34.0 b | 25.7 c | 25.3 c | 30.3 b | 57.3 c | 37.3 c | 50.0 c | 26.0 c | 67.0 b |
| *B. speciformis* | -5.3 c | -13.7 d | 4 d | -6 d | -1 d | -5.3 d | 0.7 c | 2 e | 2 d | -6 e | -2.3 d | 10 c |
| LSD $P < 0.05$ | 12.9 | | 6.2 | | 7.2 | | 5.3 | | 6.6 | | 5.4 | |

Means within a column follwed by the same letter are not different ($P < 0.05$) using the LSD mean separation procedure.

S = surface application
I = Incorporation

were incorporated. Calliandra released the least amount of N.

Incorporation of prunings released more N at 4 WAP sampling date for acacia, cajanus, and leucaena. Calliandra and miombo litter released more N when prunings were applied as mulch. Acacia and cajanus released the highest amounts of N at 4 WAP followed by calliandra, leucaena, and miombo litter when prunings were applied as mulch. All species were different from each other except acacia and cajanus. The same trend was observed when the method of application was incorporation except that miombo litter was immobilizing N from the soil (Table 3.5).

At 6 WAP, incorporation of prunings for acacia and cajanus caused more N release than surface application. For calliandra surface application released more N than incorporation. Application method had no effect on N released by leucaena and miombo litter. When prunings were surface applied, acacia and cajanus released more N than calliandra and leucaena. However when prunings were incorporated, cajanus released more than acacia. There was no difference between calliandra and leucaena in N released at 6 WAP when prunings were incorporated.

At 9 WAP, incorporation of prunings released more N than surface application for all species except miombo litter, for which method of application had no effect on N released. Within application methods, acacia and cajanus

released more N than calliandra and leucaena. However, when prunings were incorporated, N release for cajanus > acacia > leucaena > calliandra > miombo.

Method of pruning application had no effect on N released by calliandra and miombo litter at 12 WAP. Incorporation of prunings released more N than surface application for acacia, cajanus and leucaena. Cajanus and acacia were different from each other when prunings were applied as mulch. There was no difference between calliandra and leucaena in N release at 12 WAP. The same trend was observed when prunings were incorporated, except calliandra released less N than leucaena.

At final maize harvest, incorporation of prunings released more N than surface application for all species. Across application methods, species affected the amount of N released. Cajanus released more N than acacia when prunings were applied as mulch. However, there was no difference between calliandra and leucaena in N released. The same trend was observed when prunings were incorporated. Miombo litter released the least amount of N.

## Cumulative N Uptake by Maize

For most species, method of pruning application affected cumulative N uptake by maize at all sampling dates. Incorporation of prunings resulted in more N uptake for acacia, cajanus and leucaena at all sampling dates. Surface

application resulted in more N uptake for calliandra at 6 WAP and final maize harvest. Method of pruning application had no effect on cumulative N uptake for miombo litter at 12 WAP and at final maize harvest.

Within application methods, MPT species affected cumulative maize N uptake at all sampling dates. (Table 3.6) Cajanus, leucaena and miombo litter did not differ in N uptake at 4 WAP when prunings were applied as mulch. However, acacia was different from calliandra. When method of application was incorporation, N uptake was lower for acacia, calliandra and miombo than for cajanus and leucaena.

At 6 WAP, calliandra gave the highest cumulative N uptake that was > acacia > cajanus when prunings were applied as mulch. Miombo litter had lower maize N uptake than leucaena. There were no differences in N uptake by maize for acacia, cajanus and leucaena when prunings were incorporated at 6 WAP. However, miombo litter gave lower N uptake than calliandra. The control treatment had lower N uptake than all the species except miombo at 4 and 6 WAP.

When prunings were applied as mulch, the cumulative N uptake by maize at 9 WAP was of the following order: leuceana > calliandra = cajanus > acacia > miombo litter. When prunings were incorporated, the sequence was acacia > cajanus > leucaena > calliandra > miombo litter.

At final maize grain harvest all five litters gave different cumulative N uptake when prunings were applied as

Table 3.6 Nitrogen uptake by maize (kg $ha^{-1}$) as affected by method of placement and MPT species.

| SPECIES | TIME AFTER PLANTING (weeks) 4 | | 6 | | 9 | | 12 | | HARVEST | |
|---|---|---|---|---|---|---|---|---|---|---|
| | S | I | S | I | S | I | S | I | S | I |
| *A. angustissima* | 2.9 a | 1.5 c | 5.2 b | 6.2 a | 13.4 c | 29.4 a | 19.4 b | 26.8 b | 17.2 d | 46.4 b |
| *C. calothyrsus* | 2.1 b | 1.6 c | 6.6 a | 5.3 b | 17.0 b | 16.0 d | 15.6 c | 25.7 b | 36.6 b | 30.5 c |
| *C. cajan* | 1.6 c | 2.4 a | 5.2 b | 6.8 a | 17.2 b | 26.5 b | 16.6 c | 51.2 a | 41.8 a | 55.1 a |
| *L. leucocephala* | 1.6 c | 2.0 b | 3.8 c | 6.8 a | 22.2 a | 23.7 c | 22.6 a | 27.0 b | 26.4 c | 51.9 ab |
| *B. speciformis* | 1.7 c | 1.3 d | 1.3 d | 2.5 c | 5.8 d | 8.1 e | -3.5 d | -6.2 c | 7.3 e | 6.8 d |
| LSD $P < 0.05$ | 0.3 | | 0.8 | | 2 | | 3.7 | | 5.5 | |

Means within a column followed by the same letter are not different ($P < 0.05$) using the LSD mean separation procedure.

S = surface application
I = Incorporation

mulch. The pattern was: cajanus > calliandra > leucaena > acacia > miombo litter. The pattern was somewhat similar when prunings were incorporated, except that there was no difference between cajanus and leucaena. Miombo litter gave the lowest cumulative N uptake.

Nitrogen Recovery by Maize

When applied as mulch, N reccovery by maize was higher with prunings of acacia, calliandra and miombo litter; and for cajanus and leucaena, method of pruning application had no effect at 4 WAP (Table 3.7). When incorporated, only miombo litter differed from the rest of the species in terms of NIR. However, when prunings were applied as a mulch, the five species were different from each other with miombo giving the highest NIR and cajanus the least (Table 3.7).

Method of pruning application affected NIR for all species at 6 WAP. Incorporation of prunings gave higher NIR for all species except calliandra, where surface application gave higher NIR than incorporation. Across application methods, MPT species had a significant effect on NIR. Applying prunings as mulch, there was no effect on NIR among cajanus, leucaena and miombo litter. Calliandra and acacia gave higher NIR compared to the other three species. When prunings were incorporated it was only leucaena which gave higher NIR than the other three species. There was no difference between leucaena and miombo litter.

Table 3.7 Nitrogen recovery by maize as affected by method of placement and MPT species.

| SPECIES | TIME AFTER PLANTING (weeks) 4 | | 6 | | 9 | | 12 | | HARVEST | |
|---|---|---|---|---|---|---|---|---|---|---|
| | S | I | S | I | S | I | S | I | S | I |
| A. angustissima | 2.0 b | 1.1 c | 3.6 b | 4.3 b | 9.4 d | 20.5 a | 13.5 b | 18.7 c | 12.1 c | 32.4 ab |
| C. calothyrsus | 1.8 c | 1.4 b | 5.6 a | 4.5 b | 14.5 b | 12.8 d | 13.3 b | 22.0 b | 31.3 a | 26.0 b |
| C. cajan | 0.9 e | 1.3 b | 2.9 c | 3.8 b | 9.7 d | 14.9 c | 9.3 c | 28.8 a | 23.4 a | 30.9 ab |
| L. leucocephala | 1.3 d | 1.6 b | 3.0 c | 5.5 a | 17.8 a | 19.0 a | 18.1 a | 21.6 b | 21.1 ab | 35.7 a |
| B. speciformis | 3.6 a | 2.7 a | 2.4 c | 5.1 ab | 11.9 c | 16.9 b | -6.2 d | -12.9 d | 15.3 bc | 13.3 c |
| LSD $P < 0.05$ | 0.4 | | 0.9 | | 1.8 | | 2.9 | | 8.1 | |

Means within a column followed by the same letter are not different ($P < 0.05$) using the LSD mean separation procedure.

S = surface application
I = incorporation

Across the species, method of pruning application had an effect on NIR by maize at 9 and 12 WAP, and at final harvest. In general, incorporation of prunings gave higher NIR compared to surface application for most MPT species at 9 WAP, 12 WAP and final harvest. At 9 WAP, method of application had no effect on NIR for calliandra and leucaena, and for calliandra and miombo litter at final maize harvest (Table 3.7).

MPT species affected NIR within the application methods at 9 WAP, 12 WAP and final harvest. When prunings were applied as mulch, leucaena gave the highest NIR at 9 WAP > calliandra > acacia = cajanus > miombo litter. Acacia and leucaena were not different in NIR at 9 WAP. When prunings were incorporated, however, there were differences between calliandra, miombo litter and cajanus.

At 12 WAP, leucaena prunings gave the highest NIR which differed from the other four species when prunings were applied as mulch. Acacia and calliandra showed no differences in NIR. Miombo litter had a negative NIR which is indicative of net N immobilization compared to control treatment. When prunings were incorporated, cajanus gave the highest NIR (28.8%) > calliandra = leucaena > acacia > miombo litter.

The differences among species for NIR were less apparent at final harvest. When prunings were applied as mulch there were no differences in NIR among calliandra,

cajanus and leucaena, nor between acacia and miombo litter. A similar trend was observed when prunings were incorporated, except that leucaena was different from calliandra. Miombo litter gave the lowest NIR of 13.3% which was significantly different from the other four species.

## Discussion

The decomposition and nitrogen-release constants of the prunings were affected by the quality and method of application of the prunings. Decomposition constants were negatively correlated with the concentration (%) and protein binding capacity of polyphenols in the prunings ($r = -0.4$). The N-release constant was negatively correlated with protein binding capacity of the polyphenols ($r = -0.35$).

Polyphenols may bind the protein in the prunings and make them less susceptible to microbial decomposition. This suggestion is corroborated by laboratory incubation studies (Chapter 2 and Handayanto et al. 1994), where cumulative mineralized N was negatively correlated with polyphenol:N and (lignin + polyphenol):N ratios.

Incorporated prunings decomposed faster and released more N than surface applied prunings (Figures 3.2 and 3.3). The reduced rates of decomposition and N mineralization of surface applied prunings could be attributed to a combination of poor contact of the residues with soil and marked temperature- and moisture-fluctuations at soil

surface (Wilson et al. 1986, and Wilson and Hardgrove 1986). It could also have been possible that the dry spells that occurred during the growing season desiccated the surface-applied prunings to the extent that N mineralization and decomposition were greatly reduced compared to those of incorporated prunings.

Maize dry matter and grain yield (Figure 3.1) were higher in treatments where prunings were applied than for the control treatment. This indicates that MPT prunings can substantially contribute to N requirements of maize without supplemental inorganic fertilizer N. For most of the species, higher maize dry matter and grain yield were obtained when prunings were incorporated than surface-applied, with the exception of calliandra. For MPT species such as leucaena, cajanus, calliandra, and acacia, incorporated prunings had higher N-release constants than surface applied prunings (Figure 3.3) and released more N compared to surface applied prunings (Table 3.5). This could have made more N available to the maize crop as shown in Table 3.5. Other studies on alfisols in subhumid Nigeria (Kang and Duguma 1985, Zosya et al. 1990, and Mulongoy et al. 1993) also found that incorporation of MPT prunings gave higher maize yields than surface application.

Cajanus and leucaena prunings within each application method gave similar maize grain yields (Figure 3.1). In general, these two species released more N than acacia or

callandria, regardless of the application method (Table 3.5). This could have made more N available to the maize crop, hence higher grain yields. Low maize grain yield obtained from application of miombo litter can be attributed to prolonged N immobilization with this litter during most of the season (Table 3.5). The differences between grain yield among MPT species can also be attributed to different amounts of N contained in the prunings (Table 3.3).

Cumulative N uptake and NIR were affected by method of pruning application and pruning quality. Incorporation of prunings released more N than surface application during the first 4 weeks after pruning application (Table 3.5). This could be attributed to loss of the labile N from the prunings. Xu et al. (1993) and Schroth et al. (1992) found under semiarid conditions that some MPT prunings can release more than 50% of their N content during the first 4 weeks after application, followed by a phase of slow release. This pattern of N release was also evident in prunings of cajanus and acacia in this study (Table 3.5). This effect seems to be more pronounced when prunings are incorporated. Maize has a rapid growth phase from 6 to 12 WAP, which is also the phase of high N demand, until silking and grain filling stages (Karlen et al. 1988). Our results suggest that accumulation of available N in the soil before the peak period of N uptake is needed to achieve synchrony between N supply from prunings and N demand by the maize crop. This

may explain why incorporated prunings of cajanus, acacia and leucaena gave higher grain yields than surface applied (Figure 3.1 and Table 3.5). Low maize grain yield from treatments where prunings were applied as mulch could also perhaps be due to loss of N through ammonia volatilization. Higher weed growth observed in mulched treatments before weeds could be manually removed and lower N mineralization could also have led to lower maize grain yield.

For most of the species studied here, incorporation of prunings gave higher NIR values than surface application. These results can be explained by higher N release, N uptake and maize biomass production under treatments where prunings were incorporated than in surface applied treatments. Another reason could be reduction in loss due to $NH_3$ volatilization from incorporated treatments as suggested by Janzen and McGinn (1991) and Costa et al. (1990). This aspect needs further research.

The main findings of this study are that NIR by maize from MPT prunings used as a source of N can be increased by managing pruning quality and method of pruning application. Despite low NIR of farmers' MPT prunings as source of N to maize compared to inorganic N fertilizers, prunings can make significant contributions to maize grain yield without inorganic N fertilizer. Incorporation of better-quality prunings of MPT species like cajanus, leucaena and acacia increased maize grain, N release, N uptake and NIR compared

to surface application. However, this does not mean mulching should not be considered as a management practice. In situations where soil erosion is a serious problem, mulching can be beneficial. Mulching can also lower soil temperature, and increase soil moisture (Budelman 1989) which will allow early seed germination and early crop development. In situations where dry spells are a common occurrence after planting crops, mulching would be an advantage for early crop establishment (Table 3.3). In order to achieve higher NIR, it seems that there must be a large accumulation of available N before the peak demand of N by maize. This may be the way to achieve synchrony between N supply from prunings and N demand by maize. Biomass transfer systems where prunings are applied to crops without trees being grown *in situ* seem to give better NIR than alley cropping systems. The economic viability and biological sustainability of these systems needs to be tested under farmers' circumstances. Areas needing further research are to find out how much of released N is found in the soil microbial biomass, soil organic matter pools, and lost through leaching or ammonia volatilization, and the residual effect of different MPT species to subsequent crops. Such studies will inevitably need to use radioisotopes such as $^{15}N$.

CHAPTER 4
# MANAGEMENT OF MPT PRUNINGS AS A NITROGEN SOURCE TO MAIZE: PART 2. EFFECT OF TIME OF PRUNINGS APPLICATION ON MAIZE NIR

## Introduction

Chapter 3 described studies that evaluated the effect of method of pruning application; another major aspect of pruning management is time of pruning application. That is the emphasis of the studies reported in this chapter.

The timing of pruning application could be expected to have a significant effect on crop N uptake and yield. Kang and Mulongoy (1987) showed that application of gliricidia prunings 2 weeks before planting, at planting, or 2 weeks after planting resulted in more efficient use of N released and higher maize yield than prunings applied 4 or 6 WAP. However, other studies from Nigeria (IITA 1986) showed that maize grain yield and N uptake when flemingia prunings were used were not influenced by time of pruning application.

Most of the studies on time of pruning application have been conducted in the humid tropics where moisture is non-limiting during most of the year. In semiarid tropics, application of prunings before planting has several practical difficulties. The soil will be too dry to incorporate the prunings. Even if prunings were surface

applied, prunings will either be blown away by wind or eaten by termites or cattle. It would seem that the only practical way farmers could efficiently use their prunings is to apply the prunings at planting or after planting. This study was conducted to evaluate the effect of time of pruning application and pruning quality on NIR of prunings by maize. The specific objective was to determine whether synchrony between release of nutrients from prunings and uptake by crops could be achieved by manipulating the time of pruning application.

## Materials and Methods

### Site

The experiment was conducted on the ICRAF field research station at Domboshava, Zimbabwe, on the same site as that of the experiment in Chapter 3. The main soil type at this site is an alfisol (USDA classification, or lixisol under the FAO classification). The soil texture is medium sandy clay loam with 24% clay, 5% silt and 71% sand. The chemical properties of the 0-20 cm layer are: pH 4.8 ($CaCl_2$), total exchangeable bases 1.7 (me %), CEC 2.2 (me %), organic carbon 0.5%, resin extractable P 18 ppm and 38 ppm N after incubation at the beginning of the experiment. See Chapter 3 for a detailed site description.

Experimental Design and Treatments

The treatments consisted of the prunings of three MPTs species, *Calliandra calothyrsus* (CC), *Leucaena leucocephala* (LL) and 50:50 w/w mixture of calliandra and leucaena (CL) prunings, applied at planting, and at 2 and 4 WAP. There was also a control treatment where prunings were not applied.

Treatments

The following were the treatments applied:

| | | | |
|---|---|---|---|
| 1. | CC 5 W0 | = | calliandra applied @ 5 Mg $ha^{-1}$ @ planting |
| 2. | LL 5 W0 | = | leucaena applied at 5 Mg $ha^{-1}$ at planting |
| 3. | CL 5 W0 | = | calliandra/leucaena applied at 5 Mg $ha^{-1}$ at planting |
| 4. | LL 5 W2 | = | leucaena applied at 5 Mg $ha^{-1}$ at 2 WAP |
| 5. | CC 5 W4 | = | calliandra applied at 5 Mg $ha^{-1}$ at 4 WAP |
| 6. | LL 5 W4 | = | leucaena applied at 5 Mg $ha^{-1}$ at 4 WAP |
| 7. | CC W0+W2 | = | calliandra applied at 2.5 Mg $ha^{-1}$ at planting + 2.5 Mg $ha^{-1}$ at 2 WAP |
| 8. | LL W0+W2 | = | leucaena applied at 2.5 Mg $ha^{-1}$ at planting + 2.5 Mg $ha^{-1}$ at 2 WAP |
| 9. | CL W0+W2 | = | calliandra/leucaena applied at 2.5 Mg $ha^{-1}$ at planting + 2.5 Mg $ha^{-1}$ at 2 WAP |
| 10. | CC W0+W4 | = | calliandra applied at 2.5 Mg $ha^{-1}$ at planting + 2.5 Mg $ha^{-1}$ at 4 WAP |
| 11. | LL W0+W4 | = | leucaena applied at 2.5 Mg $ha^{-1}$ at planting + 2.5 Mg $ha^{-1}$ at 4 WAP |
| 12. | CL W0+W4 | = | calliandra/leucaena applied at 2.5 Mg $ha^{-1}$ at planting + 2.5 Mg $ha^{-1}$ at 4 WAP |
| 13. | CONTROL | = | no prunings applied |

A randomized complete block design with three replications was used. Details on plot size, cultural practices, and variables measured are found in Chapter 3.

Prunings Management

The prunings consisted of leaves. These prunings were analyzed for initial N, lignin, soluble polyphenols and

protein binding capacity using methods described in Chapter 3. The initial chemical composition is shown in Table 4.1.

Data Analysis

The data on above-ground dry matter accumulation, N uptake and NIR at different sampling dates, and grain yield at final harvest were subjected to ANOVA using the SAS program. Treatment means were declared different from each other at $P < 0.05$ using the Duncan's multiple range mean separation procedure. This mean separation procedure was used because of a lack of full sets of treatments on which to conduct complete contrasts.

Table 4.1 Chemical composition of the prunings applied at planting.

| *SPECIES* | *CHEMICAL COMPOSITION* | | | |
|---|---|---|---|---|
| | % N | % lignin | % soluble polyphenols | protein binding capacity |
| *Calliandra calothyrsus* | 3.83 | 18.52 | 4.24 | 12.73 |
| *Leucaena leucocephala* | 3.40 | 9.74 | 3.95 | 4.38 |
| *Calliandra + Leucaena* (1:1 mixture on weight basis) | 3.62 | 10.29 | 4.10 | 9.35 |

# Results

## Above-ground Maize Dry Matter

The application of prunings increased above-ground dry matter production of maize at all sampling dates compared to the control treatment (Table 4.2). When maize DM was sampled at 4 WAP, 5 Mg $ha^{-1}$ of leucaena or calliandra applied at planting produced the highest and similar DM accumulation. Application of a mixture of leucaena plus calliandra at 5 Mg $ha^{-1}$ at planting produced similar maize DM to applying 50% of either leucaena or calliandra at planting and 50% at 4 WAP. Similarly, applying 5 Mg $ha^{-1}$ of leucaena or calliandra at 4 WAP was not different from applying the mixture of leucaena plus calliandra 50% at planting and 50% at 4 WAP. Leucaena prunings applied at 5 Mg $ha^{-1}$ at 2 WAP produced lower maize DM compared to leucaena applied 50% at planting and 50% at 2 WAP, or 5 Mg $ha^{-1}$ at planting and at 4 WAP.

At 6 WAP, the highest DM was obtained by applying 5 Mg $ha^{-1}$ of calliandra at planting, followed by application of leucaena at 5 Mg $ha^{-1}$ at planting (Table 4.2). Mixture of leucaena plus calliandra applied at planting produced lower maize DM than either species applied alone at planting. When leucaena and calliandra were applied at 5 Mg $ha^{-1}$ at 4 WAP there were no differences in maize DM production. Leucaena applied at 5 Mg $ha^{-1}$ at 2 WAP produced higher DM than calliandra or leucaena applied at 5 Mg $ha^{-1}$ at 4 WAP.

Table 4.2 Maize dry matter yield (kg $ha^{-1}$) as affected by MPT species and time of pruning application.

| | TIME AFTER PLANTING (weeks) | | | |
|---|---|---|---|---|
| TREATMENT | 4 | 6 | 9 | 12 |
| CC 5 W0 | 309.7 a | 862.0 a | 3038.0 abc | 8751.7 a |
| LL 5 W0 | 310.7 a | 785.0 b | 2989.3 abc | 8010.3 ab |
| CL 5 W0 | 260.0 b | 645.0 d | 3129.7 ab | 6542.7 cd |
| LL 5 W2 | 148.0 f | 588.3 f | 2992.0 abc | 5722.0 de |
| CC 5 W4 | 229.3 c | 329.3 i | 3288.0 a | 5792.0 de |
| LL 5 W4 | 227.0 c | 332.0 i | 3190.3 a | 6608.7 cd |
| CC W0+W2 | 283.0 b | 494.0 g | 2607.7 cd | 7652.7 abc |
| LL W0+W2 | 129.7 g | 451.3 h | 2992.0 abc | 7272.0 bc |
| CL W0+W2 | 190.0 d | 598.3 f | 3053.0 abc | 7988.0 ab |
| CC W0+W4 | 261.0 b | 612.3 e | 2876.7 abc | 4782.0 ef |
| LL W0+W4 | 260.0 b | 662.0 c | 2868.7 abc | 4911.0 ef |
| CL W0+W4 | 228.0 c | 606.0 e | 2943.7 abc | 5112.0 ef |
| CONTROL | 172.7 e | 645.0 d | 2494.7 cd | 4279.0 f |

Means within a column follwed by the same letter are not different ($P < 0.05$) using Duncan's Multiple Range Test

CC 5 W0 = Calliandra applied at 5 t / ha at planting.
LL 5 W0 = Leucaena applied at 5 t / ha at planting.
CL 5 W0 = Calliandra and Leucaena mixture applied at 5 t / ha at planting.
LL 5 W2 = Leucaena applied at 5 t / ha at 2 weeks after planting.
CC 5 W4 = Calliandra applied at 5 t / ha at 4 weeks after planting.
LL 5 W4 = Leucaena applied at 5 t / ha at 4 weeks after planting.
CC W0+W2 = Calliandra applied at 2.5 t / ha at planting + 2.5 t/ ha at 2 weeks after planting.
LL W0+W2 = Leucaena applied at 2.5 t / ha at planting + 2.5 t/ ha at 2 weeks after planting.
CL W0+W2 = Calliandra and Leucaena mixture applied
at 2.5 t / ha at planting + 2.5 t/ ha at 2 weeks after planting.
CC W0+W4 = Calliandra applied at 2.5 t / ha at planting + 2.5 t/ ha at 4 weeks after planting.
LL W0+W4 = Leucaena applied at 2.5 t / ha at planting + 2.5 t/ ha at 4 weeks after planting.
CL W0+W4 = Calliandra and Leucaena mixture applied
at 2.5 t / ha at planting + 2.5 t/ ha at 4 weeks after planting.
CONTROL = No prunings applied.

However, with split applications (50% at planting + 50% at 2 WAP) of calliandra, leucaena, and their mixture, the mixture produced the highest DM > calliandra > leucaena. But when split application was at planting + 4 WAP, leucaena resulted in more maize DM than calliandra and the mixture produced similar maize DM to calliandra (Table 4.2).

At 9 WAP, in general, the treatments showed no differences in terms of DM accumulation except the control treatment produced less compared to leucaena or calliandra applied at 5 Mg $ha^{-1}$ at 4 WAP (Table 4.2).

When DM accumulation was determined at 12 WAP, there were no differences between calliandra and leucaena applied at 5 Mg $ha^{-1}$ at planting. However, their mixture applied at planting produced lower maize biomass than each component applied on its own at planting. There were no differences in maize DM accumulation when leucaena and calliandra were applied at 5 Mg $ha^{-1}$ at 4 WAP or leucaena applied at 5 Mg $ha^{-1}$ at 2 WAP. The mixture of leucaena and calliandra applied at planting produced similar maize DM yield as each component applied alone at 4 WAP. With the split application of 50% at planting and 50% at 2 WAP, there were no differences among leucaena, calliandra, and their mixture. The same trend was observed when split application was done at planting and at 4 WAP except that split application at planting + 2 WAP produced more maize biomass than split application at planting and 50% at 4 WAP.

Maize Grain Yield

Application of prunings increased maize grain yield compared to the control treatment (Table 4.3). The highest maize grain yield obtained with calliandra applied at 5 Mg $ha^{-1}$ at planting was 228% more than control (5.49 vs 1.67 Mg $ha^{-1}$) (Table 4.3). When calliandra and leucaena were applied at 5 Mg $ha^{-1}$ at planting, there were no differences in terms of maize grain yield. However, their mixture gave lower maize grain yield than calliandra but not leucaena. Leucaena applied at 5 Mg $ha^{-1}$ at 2 WAP gave similar grain yield to leucaena or calliandra applied at 5 Mg $ha^{-1}$ at 4 WAP and their mixture applied at planting. There was no effect of split application at planting and 50% at 2 WAP or at 4 WAP in terms of maize grain yield except leucaena applied at 50% at planting plus 50% at 4 WAP gave lower maize grain yield than the mixture applied at 50% at planting and 50% at 2 WAP (Table 4.3). The control treatment gave the lowest maize grain yield of 1.67 Mg $ha^{-1}$.

Nitrogen Uptake by Maize

Nitrogen uptake by maize was improved by pruning application and time of pruning application (Table 4.4).

Four weeks after planting

At 4 WAP sampling date, the control treatment and mixture of calliandra and leucaena applied at 5 Mg $ha^{-1}$ at

Table 4.3 Maize grain yield (Mg $ha^{-1}$) as affected by MPT species and time of pruning application.

| TREATMENT | GRAIN YIELD |
|---|---|
| CC 5 W0 | 5.49 a |
| LL 5 W0 | 5.09 ab |
| CL 5 W0 | 4.49 bc |
| LL 5 W2 | 4.65 bc |
| CC 5 W4 | 4.63 bc |
| LL 5 W4 | 4.61 bc |
| CC W0+W2 | 3.38 de |
| LL W0+W2 | 3.64 de |
| CL W0+W2 | 4.02 cd |
| CC W0+W4 | 3.29 de |
| LL W0+W4 | 3.09 e |
| CL W0+W4 | 3.52 de |
| CONTROL | 1.67 f |

Values followed by different letters in each column are significantly different from each other at $P < 0.05$ using Duncan's Multiple Range Test.

See Table 4.2 for explanation of treatments

Table 4.4 Nitrogen uptake (kg $ha^{-1}$) as affected by MPT species and time of pruning application.

| TREATMENT | TIME AFTER PLANTING (weeks) 4 | | 6 | | 9 | | 12 | | HARVEST | |
|---|---|---|---|---|---|---|---|---|---|---|
| CC 5 W0 | 1.6 | cd | 12.2 | a | 26.2 | ab | 26.5 | a | 46.5 | a |
| LL 5 W0 | 2.7 | b | 8.7 | c | 22.4 | b | 18.6 | b | 35.6 | bc |
| CL 5 W0 | 3.2 | ab | 10.7 | b | 27.7 | a | 23.6 | ab | 31.9 | c |
| LL 5 W2 | -0.6 | g | 4.3 | d | 29.5 | a | 22.4 | ab | 35.8 | bc |
| CC 5 W4 | 1.1 | def | -3.3 | h | 13.4 | c | 20.0 | b | 36.5 | bc |
| LL 5 W4 | 1.6 | c | -4.2 | h | 11.4 | c | 23.0 | ab | 37.7 | b |
| CC W0+W2 | 1.4 | cd | 0.7 | f | 13.3 | c | 27.4 | a | 27.1 | d |
| LL W0+W2 | -0.1 | g | -1.0 | g | 13.2 | c | 17.3 | b | 20.1 | ef |
| CL W0+W2 | 0.7 | f | 2.1 | ef | 13.3 | c | 23.5 | ab | 33.0 | bc |
| CC W0+W4 | 1.8 | c | 2.5 | e | 22.9 | b | 23.1 | ab | 19.9 | ef |
| LL W0+W4 | 0.9 | ef | 2.2 | e | 21.7 | b | 18.1 | b | 18.7 | f |
| CL W0+W4 | -1.0 | g | 2.9 | e | 25.3 | ab | 22.9 | ab | 24.2 | de |
| CONTROL | 3.6 | a | 10.7 | b | 26.6 | ab | 22.6 | ab | 20.9 | ef |

Values followed by different letters in each column are significntly different from each other at $P < 0.05$ using Duncan's Multiple Range Test

See Table 4.2 for explanation of treatments.

planting showed the highest N uptake. There were no differences between leucaena and the mixture applied at planting in terms of N uptake although calliandra applied at 5 Mg $ha^{-1}$ at planting had lower N uptake than the two. When leucaena was applied at 5 Mg $ha^{-1}$ at 2 WAP or 50% at planting plus 50% at 2 WAP, and the mixture of calliandra and leucaena 50% at planting and 50% at 4 WAP, these treatments had negative N uptake values compared to control showing that there was net N immobilization in these treatments.

Six weeks after planting

At 6 WAP, calliandra applied at planting resulted in the highest N uptake by maize followed by the mixture and leucaena, all 5 Mg $ha^{-1}$. N uptake by maize at 6 WAP was lower when leucaena prunings at 5 Mg $ha^{-1}$ were applied 2 WAP than applied at planting. When 5 Mg $ha^{-1}$ calliandra or leucaena were applied at 4 WAP they showed no differences in N uptake. Both showed net N immobilization compared to the control treatment (Table 4.4). With split application of calliandra, leucaena and their mixture, 50% at planting plus 50% at 2 WAP, there were no differences between calliandra and the mixture. Leucaena prunings continued to show net N immobilization. When the same split application was done 50% at planting plus 50% at 4 WAP there were no differences among calliandra, leucaena and their mixture. However, N uptake by these treatments were higher than those of 50% at planting plus 50% at 2 WAP treatments (Table 4.4).

Nine weeks after planting

At 9 WAP highest N uptake values were obtained in treatments where all prunings were applied at planting. There were no differences in terms of N uptake between calliandra and leucaena treatments. When all prunings were applied at planting at 5 Mg $ha^{-1}$, leucaena gave lower uptake than the mixture, which was equal to calliandra. Leucaena at 5 Mg $ha^{-1}$ resulted in more N uptake by maize when applied at 2 WAP than at planting, and was similar to that of calliandra or mixture application at planting.

Applying leucaena or calliandra at 5 Mg $ha^{-1}$ at 4 WAP gave N uptake values similar to those of treatments with split application of 50% at planting and 50% at 2 WAP (Table 4.4). Treatments with split application of 50% at planting and 50% at 4 WAP showed no significant differences among themselves. However, they gave higher N uptake values compared to treatments where 50% was applied at planting and 50% at 2 WAP or 5 Mg $ha^{-1}$ of calliandra or leucaena all applied at 4 WAP.

Twelve weeks after planting

Most of the treatments showed no differences at 12 WAP in terms of N uptake (Table 4.4). Leucaena applied at planting or 50% at planting and 50% at 2 WAP or 4 WAP gave lower N uptake values than calliandra at 5 Mg $ha^{-1}$ applied at planting or 50% at planting plus 50% at 2 WAP.

Maize harvest stage

At maize grain harvest, calliandra applied at 5 Mg $ha^{-1}$ at planting gave the highest total N uptake which was different from leucaena and the mixture applied all 5 Mg $ha^{-1}$ at planting. However, there was no difference between leucaena applied at planting or all applied at 2 WAP and the mixture applied at 5 Mg $ha^{-1}$ at planting. Calliandra and leucaena applied at 4 WAP showed no differences in terms of N uptake between themselves and leucaena applied at 5 Mg $ha^{-1}$ at planting or at 2 WAP. Split application at 50% at planting and 50% at 2 WAP resulted in differences among the three treatment sets. Mixture caused the highest N uptake followed by calliandra, and the least N uptake was with leucaena (Table 4.4). With split application at planting and 50% at 4 WAP, the mixture gave the highest N uptake followed by calliandra and leucaena, with no differences between leucaena and calliandra.

Nitrogen Recovery by Maize (NIR)

Four weeks after planting

AT 4 WAP, applying leucaena or its mixture at 5 Mg $ha^{-1}$ at planting gave the highest NIR compared to the rest of the treatments. Applying all calliandra prunings at planting gave % N recovery values similar to those of applying leucaena at 5 Mg $ha^{-1}$ at 4 WAP or 50% calliandra at planting plus 50% at 2 WAP or at 4 WAP. Applying leucaena 5 Mg $ha^{-1}$ at

2 WAP or 50% at planting and 50% at 2 WAP and mixture at 50% at planting plus 50% at 4 WAP resulted in negative NIR indicating net N immobilization compared to the control treatment (Table 4.5).

<u>Six weeks after planting</u>

A mixture of leucaena and calliandra applied 5 Mg $ha^{-1}$ at planting gave the highest NIR followed by calliandra and leucaena ($P<0.05$). Leucaena applied 5 Mg $ha^{-1}$ at 2 WAP gave a lower NIR compared to applying at planting. Leucaena and calliandra applied 5 Mg $ha^{-1}$ at 4 WAP showed negative NIR indicating N immobilization with leucaena having higher net immobilization than calliandra. This N immobilization effect was also shown when leucaena was applied at 50% at planting plus 50% at 2 WAP. There was no effect on NIR with split application of 50% at planting and 50% at 4 WAP (Table 4.5).

<u>Nine weeks after planting</u>

At 9 WAP there was no significant effect on NIR with the application of all prunings of calliandra or leucaena and their mixture at planting on NIR. However, 5 Mg $ha^{-1}$ leucaena applied at 2 WAP gave higher NIR than calliandra or leucaena applied at planting but it was similar to the mixture applied at planting. Applying 5 Mg $ha^{-1}$ prunings of calliandra or leucaena at 4 WAP showed no difference on NIR between themselves or when compared to split application of 50% at planting plus 50% at 2 WAP (Table 4.5). Similarly, split application treatments of 50% at planting plus 50% at

Table 4.5 Nitrogen recovery (%) as affected by MPT species and time of pruning application.

| | TIME AFTER PLANTING (weeks) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| TREATMENT | 4 | | 6 | | 9 | | 12 | | HARVEST | |
| CC 5 W0 | 0.9 | bc | 7.1 | b | 15.3 | bc | 15.5 | ab | 27.2 | a |
| LL 5 W0 | 1.8 | a | 5.7 | c | 14.7 | bc | 12.1 | abc | 23.3 | bc |
| CL 5 W0 | 2.0 | a | 9.6 | a | 17.1 | ab | 14.6 | abc | 19.7 | d |
| LL 5 W2 | -0.4 | g | 2.8 | d | 19.3 | a | 14.6 | abc | 23.4 | bc |
| CC 5 W4 | 0.6 | de | -1.9 | h | 7.5 | d | 11.1 | c | 21.3 | cd |
| LL 5 W4 | 1.0 | b | -2.7 | i | 7.4 | d | 14.9 | abc | 24.6 | ab |
| CC W0+W2 | 0.8 | bcd | 0.4 | f | 7.8 | d | 16.0 | a | 15.9 | e |
| LL W0+W2 | -0.4 | g | -0.7 | g | 8.6 | d | 11.3 | c | 13.1 | fg |
| CL W0+W2 | 0.5 | e | 1.3 | e | 7.1 | d | 14.5 | abc | 20.4 | cd |
| CC W0+W4 | 1.1 | b | 1.4 | e | 13.4 | c | 13.5 | abc | 11.9 | g |
| LL W0+W4 | 0.6 | cde | 1.4 | e | 13.2 | bc | 11.8 | bc | 12.2 | fg |
| CL W0+W4 | -0.6 | g | 1.8 | e | 15.7 | bc | 13.8 | abc | 14.9 | f |

Values followed by different letters in each column are significntly different from each other at $P < 0.05$ using Duncan's Multiple Range Test

See Table 4.2 for explanation of treatments.

4 WAP showed no differences among themselves in NIR.

Twelve weeks after planting

During the 12 WAP sampling date, most treatments showed no differences on NIR (Table 4.5). However, calliandra applied at 5 Mg $ha^{-1}$ at 4 WAP and leucaena applied at 50% at planting and 50% at 2 WAP gave lower NIR compared to calliandra applied at 5 Mg $ha^{-1}$ at planting or 50% at planting and 50% at 2 WAP.

Final Harvest

There were treatment differences in NIR (Table 4.5): applying calliandra 5 Mg $ha^{-1}$ at planting gave the highest NIR of 27.2%. The mixture of the two applied at planting gave the smallest NIR which was different from each species applied alone at planting. Leucaena applied at 5 Mg $ha^{-1}$ at 2 WAP gave similar NIR as leucaena applied at 5 Mg $ha^{-1}$ either at planting or at 4 WAP. There was a difference in NIR when calliandra and leucaena were applied at 5 Mg $ha^{-1}$ at 4 WAP, with leucaena giving higher NIR than calliandra.

With split application of 50% at planting plus 50% at 2 WAP, the mixture gave the highest NIR followed by calliandra and leucaena (Table 4.5). However, with split application of 50% at planting plus 50% at 4 WAP, with the mixture and leucaena gave similar NIR values, which were higher than that from calliandra. Split applications of 50% at planting and 50% at 4 WAP gave lower NIR than split applications of 50% at planting and 50% at 2 WAP.

## Discussion

The results of this study have shown that time of pruning application and amount of prunings applied are important factors for improving maize grain yield (Table 4.3), N uptake (Table 4.4) and NIR (Table 4.5).

The time of pruning application and the amount of prunings applied affected dry matter accumulation and N uptake of maize. Application of 5 Mg $ha^{-1}$ of leucaena and calliandra prunings, either alone or in equal proportions, at planting increased maize DM yield, grain yield, N uptake, and NIR compared to application at 2 or 4 WAP. Application of calliandra at 5 Mg $ha^{-1}$ at 4 WAP reduced maize grain yield compared to application of 5 Mg $ha^{-1}$ calliandra at planting. More N is available to the maize crop during the peak N demand period (6-12 WAP) when prunings are applied at planting than when prunings are applied 4 WAP (Table 4.4). However, with leucaena there were no differences in maize grain yield, N uptake, and NIR when prunings were applied at planting or at 2 and 4 WAP. Leucaena prunings are of relatively higher quality than those of calliandra (Table 4.1). Leucaena prunings therefore could have released N before maize N peak demand (Table 3.4, Chapter 3). Hence, prunings applied at planting, 2 WAP, or 4 WAP would release some N to meet the maize N requirements. Similar results were found in the subhumid tropics of Nigeria on alfisols

(Kang and Mulongoy 1987, and IITA 1986). However, with lower quality prunings like calliandra, application too long after planting resulted in significantly lower maize grain yield, N uptake, and NIR (Tables 4.3, 4.4 and 4.5).

Application of a mixture of calliandra and leucaena prunings did not improve maize DM accumulation, grain yield, and NIR compared to each species alone. There could be two reasons for this: 1) the N released from rapidly-decomposing species like leucaena is immobilized by microbes to decompose the slow-decomposing species, hence unavailable to the maize crop, and, 2) the MPT species did not differ much in chemical composition of their prunings.

Split application of pruning at 50% planting or 50% at 2 WAP or at 4 WAP did not give better maize grain yield, N uptake and NIR than applying the whole amount at planting or at 2 WAP or at 4 WAP. When leucaena was split applied, there was N immobilization early in the season compared to applying all the available prunings at planting (Table 4.5). Split application of prunings may not have released enough N to meet the demand for microbial growth and the maize crop.

The application of prunings can contribute to N requirements of a maize crop. Applying all prunings at planting gave the highest maize grain yield, N uptake, and NIR with calliandra. However, with leucaena, prunings applied at planting, 2 WAP, or 4 WAP did not differ in terms of maize grain yield, N uptake or NIR. Split application of

prunings too long after planting the crop, like at 4 WAP, results in less N being utilized by the maize crop. However, late application may have more residual effect. This was supported by results from pot studies (see Chapter 5).

There was no advantage gained in terms of NIR and maize grain yield by application of mixtures compared to each species applied alone. The same trend was observed with split application compared to application of the entire amount of available prunings.

One aspect that needs further research is to determine the residual effect of prunings applied at different times to subsequent crops.

# CHAPTER 5
# INTERACTIONS OF PRUNING QUALITY AND TIME AND METHOD OF APPLICATION IN TWO SOIL TYPES

## Introduction

The importance of MPT prunings as sources of plant nutrients, especially N, in tropical crop production has been discussed in the previous chapters. The rate at which the applied prunings decompose and make the nutrients available to the current crop is an important factor that determines the success of this technology.

Three main factors affect N mineralization from organic residues: chemical composition of the residues, cultural practices (i.e., method and rate of application), and soil properties. Most of the studies that have been conducted so far have been single-location experiments (Mugendi et al. 1994; Jama et al. In Press). Many of the studies have been done on base-rich alfisols (Nair et al. 1994). Sandy soils which are low in soil organic matter dominate the semiarid tropical agroecological zones. There is a need for information on how prunings of leguminous trees mineralize N in soils of different soil textures.

The build-up of soil organic matter (SOM) is determined by the amount and quality of the prunings applied and their

decomposition rate (Ladd et al. 1983). Significant correlations have been found between SOM build up and soil texture (Spain 1990). Many studies have shown that organic residues decompose slowly in soils with higher clay content (Sorensen 1975; Xhu et al. 1988). However, from the results of 12 field experiments in the semiarid climate in Australia, Amato et al. (1987) found no influence of soil physical and chemical properties on the amount of $^{15}N$ released from leguminous residues. There seem to be conflicting results on the effect of soil type on N mineralization from plant residues.

Most of the studies which have reported low NIR of prunings as a source of N to crops have not examined the residual effect of pruning application on crop yields (Xu et al. 1993, and Kang et al. 1981). The N contribution from plant residues applied to a previous crop has been reported to be 1-4% of the N content of the material originally applied (Ladd et al. 1983; Janzen et al. 1990). Mulongoy and Sanginga (1990) found that the current maize crop recovered 15% of the N in leucaena prunings with 23% of the N found in soil organic N pool. High quality, fast-decomposing prunings will mineralize N quickly and can contribute more N to the current crop without much contribution to SOM buildup. It can be hypothesized that low-quality prunings which decompose slowly may, on the other hand, have a greater residual effect. This effect also may depend on soil type,

and time and method of pruning application. This study was therefore designed to test this hypothesis and determine how pruning quality, time and method of application, and soil type affect N recovery and the residual effects on maize N uptake and NIR.

## Materials and Methods

### Experimental Details

Two pot experiments were conducted in the greenhouse at Harare Research Centre in Zimbabwe from January to May 1994. The treatments were a combination of three factors namely:

Factor A: Three MPT species: *Acacia angustissima* (acacia), *Flemingia macrophylla* (flemingia), and *Cajanus cajan* (cajanus).

Factor B: Two methods of pruning application: surface mulching *vs*. incorporation in the top 15 cm of the pot.

Factor C: Three times of pruning application, at planting, 2 weeks after planting (WAP) and 4 WAP.

Two soil types, alfisols from Domboshava ICRAF Experiment Station and psamments from Makoholi Experiment Station, both in Zimbabwe, were used. Makoholi Experiment Station is in an agroecological zone with a mean annual rainfall of 650 mm, whereas Domboshava is in a zone with an annual rainfall of 750 mm.

The total number of treatment combinations were 19 per soil type including a control with no prunings applied. Two

separate experiments were conducted, one with each soil type. The experiments were arranged in a randomized complete block design replicated three times. One hundred seventy-one pots were used in each experiment to allow three destructive harvests at 6, 9, and 12 WAP. The pots which were harvested at 12 WAP were replanted with maize two days after harvest. The maize was allowed to grow 6 weeks before harvest to assess treatment residual effects on maize growth. The sampling date for this will be referred to as 18 WAP.

### Soil and Pot Management

Top soil from 0-20 cm depth was collected from Domboshava station and the Makoholi station. The chemical and physical properties of the two soils are shown in Table 5.1. The soil was sun-dried and sieved through 4-mm mesh. Asbestos pots of 30 cm diameter and 30 cm height were used. Each pot was filled with 7.8 kg soil. Plant materials (prunings) were applied, 70 g dry weight pot$^{-1}$, either on soil surface, as mulch, or soil-incorporated. In the case of incorporation, the top 15 cm of soil was tipped off at planting and thoroughly mixed with prunings prior to repotting. In the treatments with incorporation after planting, the prunings were mixed with the top 0-15 cm soil in the pot using sharp wooden trowels.

After pruning application, 4 seeds of maize hybrid cultivar R215 were planted to each pot. Fertilizers were

Table 5.1 Soil characteristics at beginning of the experiment.

| *Soil Characteristics* | *Makoholi (Psamments)* | *Domboshava (Alfisols)* |
|---|---|---|
| Texture | coarse sandy | medium sandy clay loam |
| clay % | 5.0 | 21.0 |
| silt % | 3.0 | 4.0 |
| sand % | 92.0 | 75.0 |
| pH ($CaCl_2$) | 3.9 | 4.8 |
| total exchange bases (me%) | 0.8 | 0.9 |
| CEC (me%) | 0.8 | 1.6 |
| organic carbon % | 0.29 | 0.61 |
| resin extractable P (ppm) | 7.0 | 10.0 |
| available N after incubation (ppm) | 20.0 | 29.0 |

added at 40 kg P $ha^{-1}$ as single superphosphate and 60 kg K $ha^{-1}$ as muriate of potash to all treatments. Fertilizer calculations were based on surface area of the pot. No inorganic N fertilizer was applied to any pot. Maize plants were thinned to 2 plants $pot^{-1}$ one week after emergence.

Prunings Used

Prunings consisting of leaves of the three woody leguminous species were used in the study. Prunings were cut from fodder banks grown at Domboshava Research Station and sun dried for 3 days. Samples were oven dried at 65°C for 48 hr for dry matter (DM) determination. Results of chemical

analyses will be reported on % DM basis. They were analyzed for initial N, lignin, soluble polyphenols, and protein binding capacity using methods described in Chapter 2.

Plant Harvesting and Chemical Analysis

Three plants of each treatment were destructively harvested at 6, 9, and 12 WAP, and at 18 WAP for estimating residual effects of pruning application. Maize tops were cut at soil level. The oven dried samples were ground to pass a 2-mm mesh and analyzed for N concentration. Maize N uptake was calculated as shoot dry weight multiplied by % N concentration. The NIR was calculated as N uptake in treatments where prunings were applied minus N uptake in the control. This was divided by the amount of N in the material that was initially applied, and multiplied by 100.

The data were analyzed using SAS. Treatment means were declared significant at $P<0.05$ using the Least Significant Difference mean separation procedure.

## Results

The prunings used in this study varied in chemical quality (Table 5.2). Their N concentration was in the order acacia > cajanus > flemingia. Lignin concentration ranged 8.76-22.8%. Considering low lignin, high N, and low polyphenols as indicators of good mulch quality (see Table 2.4), the species were ranked cajanus > acacia > flemingia.

Table 5.2 Chemical composition of the prunings used.

| *MPT species* | *CHEMICAL COMPOSITION* | | | |
|---|---|---|---|---|
| | % N | % lignin | % soluble polyphenols | protein binding capacity |
| Acacia angustissima | 4.38 | 8.76 | 3.35 | 3.92 |
| Flemingia macrophylla | 2.32 | 22.80 | 3.31 | 5.90 |
| Cajanus cajan | 3.95 | 12.56 | 1.19 | 2.56 |

At all sampling dates, shoot dry weight, N uptake, and NIR were significantly affected by a species x method x time -of-pruning-application interaction ($P<0.05$) on both soils. Two factor interactions will be reported in order to follow effects of method x species, time x species, and method x time of application on shoot dry weight, N uptake, and NIR which were also different at $P < 0.05$ at all sampling dates.

Maize Shoot Dry Weight (SHDW)

Method of application x MPT spp interaction on SHDW

In general, the Makoholi soil gave lower SHDW and N uptake than Domboshava soil at all sampling dates. Incorporation of prunings produced more SHDW than surface application (Figure 5.1) at all sampling dates except 9 WAP. The exception was with flemingia where method of pruning application had no effect on SHDW at 9 WAP. Across

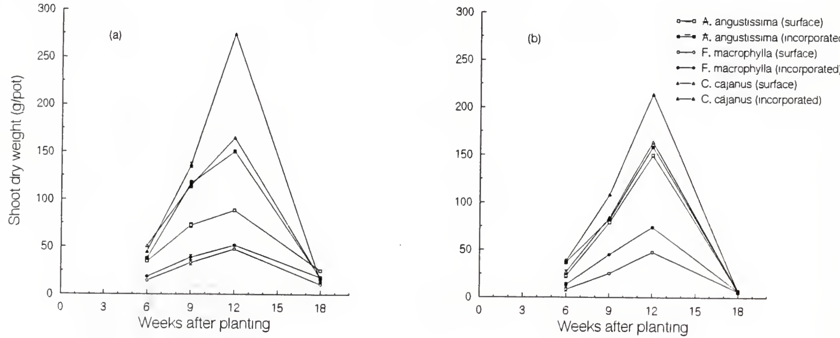


**Figure 5.1 Shoot dry weight as affected by species and method of pruning application on (a) Domboshava and (b) Makoholi soils.**

application methods, SHDW was of the order cajanus > acacia > flemingia at most sampling dates except at 18 WAP. At this sampling date the residual effects on SHDW were being tested. In the Domboshava soil, surface application of acacia and cajanus gave more SHDW than their incorporation whereas with flemingia, incorporation gave more SHDW. Incorporation gave more SHDW with all species in Makoholi soil than surface application. SHDW among species was of the order acacia > flemingia > cajanus with both application methods. With Domboshava soil, the order was acacia > cajanus > flemingia when prunings were surface applied. However the SHDW order was reversed when incorporated: acacia > flemingia > cajanus.

MPT spp x time of application on SHDW

Across application times, cajanus gave more SHDW than acacia > flemingia at each application time with both soil types (Figure 5.2). For each species, the effect of time of pruning application on SHDW was in the order: at planting > 2 WAP > 4 WAP. However there were a few exceptions to this trend with Domboshava soil. At 6 WAP pruning application time had no significant effect on SHDW with flemingia. Applying prunings at 2 WAP gave similar SHDW to applying prunings at 4 WAP with flemingia at 12 WAP. With cajanus applying prunings at 2 WAP gave significantly lower SHDW than applying at 4 WAP at 12 WAP sampling date.

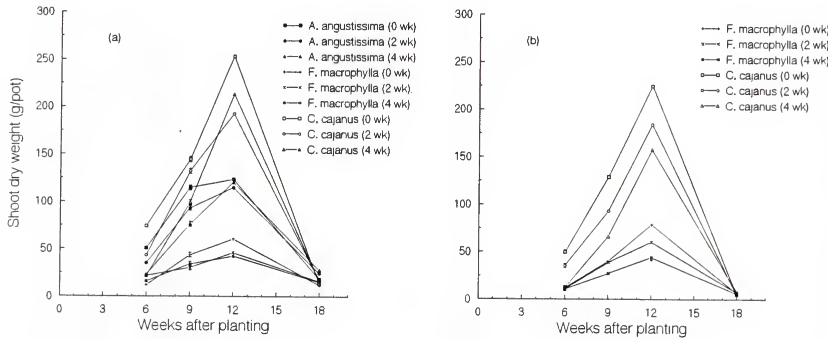


Figure 5.2 Shoot dry weight as affected by species and time of pruning application on (a) Domboshava and (b) Makoholi soils.

The residual effects showed different patterns with the two soil types. With Makoholi soil type, within application times, applying prunings of acacia and flemingia at planting gave significant SHDW than that of cajanus. However when prunings were applied at 2 WAP flemingia > acacia > cajanus whereas at 4 WAP acacia and cajanus were > flemingia. With Domboshava soil, for each application time, acacia > cajanus = flemingia in terms of SHDW. Within species, application of prunings at 4 WAP > 0 WAP > 2 WAP for acacia and cajanus and for flemingia applying at 2 WAP > 0 WAP > 4 WAP in terms of SHDW with Makoholi soil. With Domboshava soil application of prunings at 4 WAP > 2 WAP > 0 WAP for acacia and cajanus whereas for flemingia applying at 2 WAP = 4 WAP > 0 WAP in terms of residual effect on SHDW.

Method x time of pruning application interaction on SHDW

Incorporation of prunings gave significantly more SHDW than surface application at all application times and with both soil types (Table 5.3 and 5.4). Across application times, SHDW was in the order: applying prunings at planting > 2 WAP > 4 WAP (Table 5.3 and 5.4). The exception was with Makoholi soil with surface application where there was no effect on SHDW between applying at 2 WAP and 4 WAP at 12 WAP sampling date.

The residual effects on SHDW at 18 WAP differed between the two soil types with regard to the effect of application method. With Domboshava soil, when prunings were applied at

Table 5.3 Effect of method and time of pruning application on shoot dry weight (g pot$^{-1}$ Domboshava soil).

| TIME OF APPL. | SAMPLING DATE | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 6 WAP | | 9 WAP | | 12 WAP | | 18 WAP | |
| | S * | I * | S | I | S | I | S | I |
| *0 WAP* | 43.2 | 50.2 | 93.3 | 111.0 | 113.7 | 177.9 | 15.4 | 13.7 |
| *2 WAP* | 30.8 | 36.1 | 71.1 | 99.5 | 93.8 | 141.8 | 19.3 | 19.0 |
| *4 WAP* | 19.2 | 21.5 | 58.1 | 81.9 | 93.8 | 157.0 | 18.1 | 21.6 |
| LSD (P < 0.05) | 2.3 | | 3.6 | | 1.2 | | 1.3 | |

Table 5.4 Effect of method and time of pruning application on shoot dry weight (g pot$^{-1}$ Makoholi soil).

| TIME OF APPL. | SAMPLING DATE | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 6 WAP | | 9 WAP | | 12 WAP | | 18 WAP | |
| | S * | I * | S | I | S | I | S | I |
| *0 WAP* | 28.3 | 45.0 | 82.9 | 97.5 | 126.1 | 200.1 | 6.2 | 6.0 |
| *2 WAP* | 19.4 | 28.6 | 73.2 | 72.1 | 117.3 | 139.5 | 5.6 | 6.5 |
| *4 WAP* | 10.0 | 15.4 | 38.5 | 60.3 | 106.7 | 118.0 | 6.9 | 7.3 |
| LSD (P < 0.05) | 2.6 | | 1.5 | | 1.3 | | 0.3 | |

planting or at 4 WAP, surface application gave greater SHDW than incorporation. When applied at 2 WAP there was no effect of application method on SHDW. Incorporation of prunings at 2 WAP and 4 WAP gave more residual SHDW than surface application with Makoholi soil. However when prunings were applied at planting, method of pruning application had no effect on residual SHDW. With both soil types and within each application method, the applying prunings in terms of residual effect on SHDW was of the order: 4 WAP > 2 WAP > 0 WAP.

Nitrogen Uptake

Method x species interaction

Incorporation of prunings gave higher N uptake than surface application with both soil types (Figure 5.3) at all sampling dates. Across application methods, there was more N uptake from cajanus pots than acacia, and uptake from flemingia was the least. With Domboshava soil, surface application of flemingia prunings immobilized N at 6 WAP and 9 WAP whereas no N immobilization was observed with Makoholi soil.

For acacia and flemingia on the Domboshava soil, and cajanus and flemingia on the Makoholi soil, incorporation of prunings gave significantly higher N uptake than surface application at 18 WAP. Surface application gave higher residual N uptake with cajanus on Domboshava soil and with

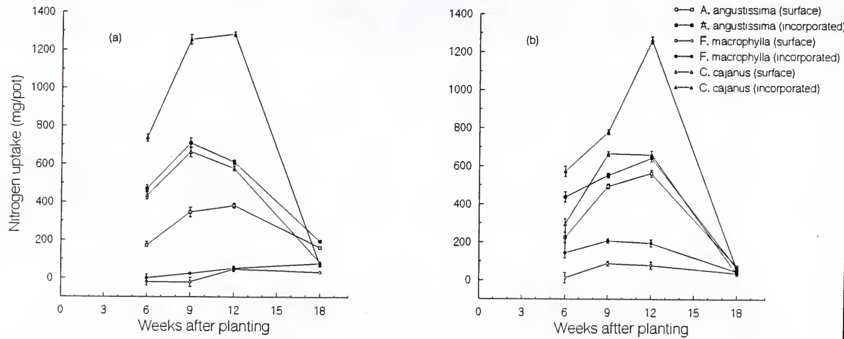


Figure 5.3 Nitrogen uptake as affected by species and method of pruning application on (a) Domboshava and (b) Makoholi soils.

acacia on Makoholi soil. When prunings were surface applied, N uptake by the second crop was in the order: acacia > cajanus > flemingia with Domboshava soil, whereas there was no significant effect of species with Makoholi soil. However when prunings were incorporated, N uptake was in the order, acacia > flemingia > cajanus with Domboshava soil whereas for Makoholi soil, it was acacia > cajanus > flemingia.

Incorporation of prunings of acacia and flemingia on Domboshava soil and cajanus and flemingia on Makoholi soil gave better N uptake than surface application. Surface application of cajanus and acacia gave higher N uptake on the two soils than their incorporation.

Time x species interaction

At all application times, cajanus gave highest N uptake followed by acacia and flemingia on both soil types (Figure 5.4). Across species, application of prunings at planting gave significantly higher N uptake > 2 WAP > 4 WAP with few exceptions. The exception was with flemingia which immobilized N with Domboshava soil when applied at planting or at 4 WAP, as recorded at 6 WAP. At 9 WAP, application time had no effect on N uptake with flemingia. With cajanus, applying prunings at planting had no significant effect on N uptake compared to applying at 2 WAP. The same effect was observed with acacia on Makoholi soil at 9 WAP. With cajanus on both soil types, applying prunings at planting gave higher N uptake > 4 WAP > 2 WAP at 12 WAP. Applying prunings

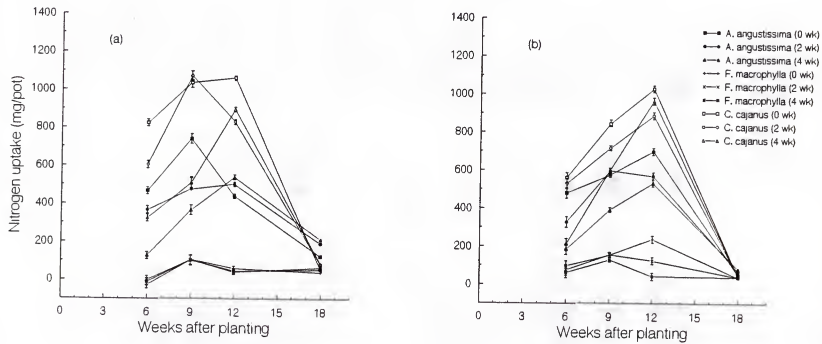


Figure 5.4 Nitrogen uptake as affected by species and time of pruning application on (a) Domboshava and (b) Makoholi soils.

of flemingia on Domboshava soil at 2 WAP gave similar N uptake with prunings applied at 4 WAP.

Across application times, N uptake was in the order: acacia > cajanus > flemingia. Application time had no effect on N uptake by the second crop on Makoholi soil with cajanus and flemingia. Applying prunings at 4 WAP gave greater N uptake > at 2 WAP > at planting with acacia on Makoholi soil. For acacia and flemingia, applying prunings at 4 WAP gave greater N uptake than at 2 WAP > applying at planting whereas for cajanus, applying at 4 WAP = 2 WAP > applying at planting with Domboshava soil.

<u>Time x method interaction</u>

Incorporation of prunings gave significantly higher N uptake than surface application with both soil types at all application times (Tables 5.5 and 5.6). Within each application method, application of prunings at planting gave higher N uptake > 2 WAP > 4 WAP with few exceptions. With Domboshava soil when prunings were surface applied at planting there was no significant effect on N uptake compared to prunings applied at 2 WAP at 9 WAP sampling date. When prunings were surface applied at 4 WAP they gave higher N uptake than when applied at 2 WAP.

N uptake was higher for incorporated prunings at all application times with Domboshava soil, whereas with Makoholi soil, it was only when prunings were applied at 4 WAP. Method of pruning application had no effect on N uptake

Table 5.5 The effect of method and time of pruning application on nitrogen uptake (mg pot$^{-1}$ Domboshava soil).

| TIME OF APPL. | SAMPLING DATE | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 6 WAP | | 9 WAP | | 12 WAP | | 18 WAP | |
| | S * | I * | S | I | S | I | S | I |
| *0 WAP* | 336.1 | 517.0 | 398.6 | 858.0 | 338.2 | 705.0 | 68.3 | 82.3 |
| *2 WAP* | 188.8 | 460.8 | 387.5 | 715.3 | 306.9 | 613.8 | 100.1 | 121.1 |
| *4 WAP* | 61.4 | 229.8 | 202.9 | 624.1 | 228.9 | 625.8 | 107.3 | 137.7 |
| LSD (P < 0.05) | 25.9 | | 35.1 | | 16.9 | | 8.4 | |

Table 5.6 The effect of method x time of pruning application on nitrogen uptake (mg pot$^{-1}$ Makoholi soil).

| TIME OF APPL. | SAMPLING DATE | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 6 WAP | | 9 WAP | | 12 WAP | | 18 WAP | |
| | S * | I * | S | I | S | I | S | I |
| *0 WAP* | 229.0 | 531.3 | 484.0 | 567.7 | 451.7 | 862.4 | 46.0 | 45.8 |
| *2 WAP* | 218.8 | 404.3 | 460.9 | 522.5 | 418.5 | 640.3 | 52.1 | 54.0 |
| *4 WAP* | 87.2 | 221.2 | 334.4 | 416.9 | 431.7 | 598.8 | 46.4 | 69.1 |
| LSD (P < 0.05) | 37.8 | | 17.1 | | 18.5 | | 4.6 | |

when applied at planting and at 2 WAP. With both application methods, applying prunings at 4 WAP gave greater N uptake than applying 2 WAP and at planting on Domboshava soil. However with Makoholi soil, this effect was only found in the incorporation treatments, whereas surface application had no effect on N uptake.

Nitrogen Recovery by Maize

Method x species interaction

Incorporation gave significantly higher NIR than surface application for all species on both soil types at all sampling dates (Figures 5.5 to 5.8). Across application methods, cajanus gave the highest NIR followed by acacia and flemingia gave the least NIR.

Time x species interaction

At each application time, the same trend was observed on species with regard to NIR (Figures 5.9 to 5.11). For each species, applying prunings at planting gave higher NIR > 2 WAP > 4 WAP with few exceptions. For flemingia and acacia on Makoholi soil, applying prunings at planting and 2 WAP were not different in NIR at 9 WAP.

Cajanus prunings applied at planting gave the highest NIR on both soils, followed by 4 WAP, which was greater than 2 WAP. However, with acacia on Domboshava soil, NIR at 12 WAP was of the order: 4 WAP > 2 WAP > applied at planting.

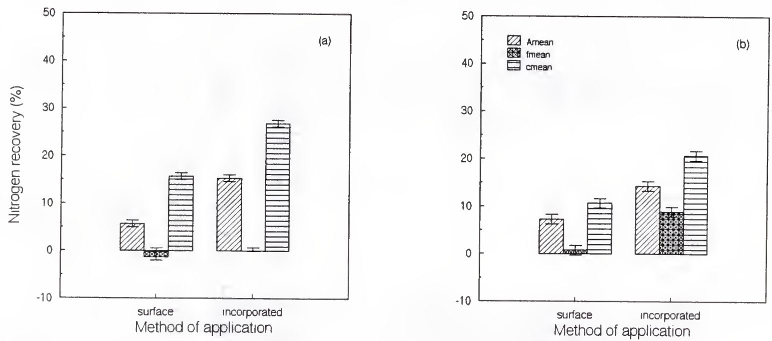


Figure 5.5 Percent nitrogen recovery by maize as affected by MPT species and method of pruning application at 6 weeks after planting on (a) Domboshava and (b) Makoholi soils.

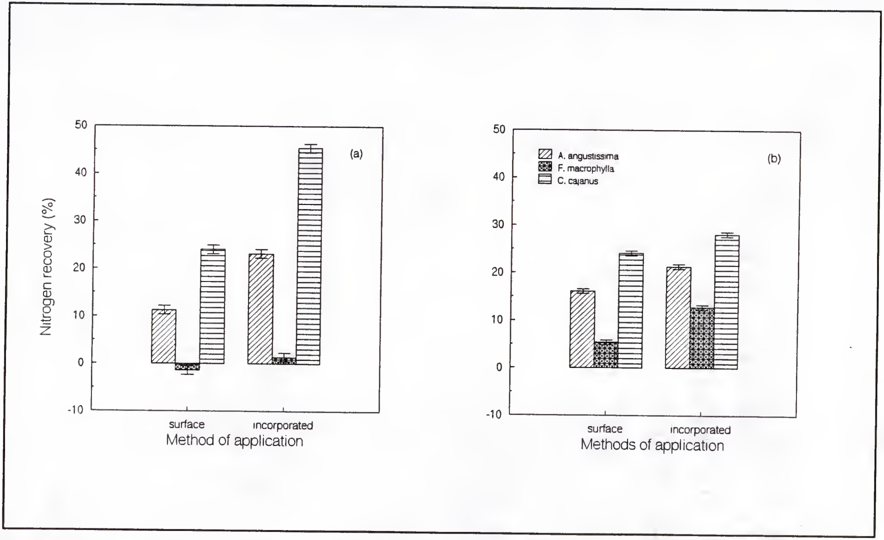


Figure 5.6 Percent nitrogen recovery by maize as affected by MPT species and method of pruning application at 9 weeks after planting on (a) Domboshava and (b) Makoholi soils.

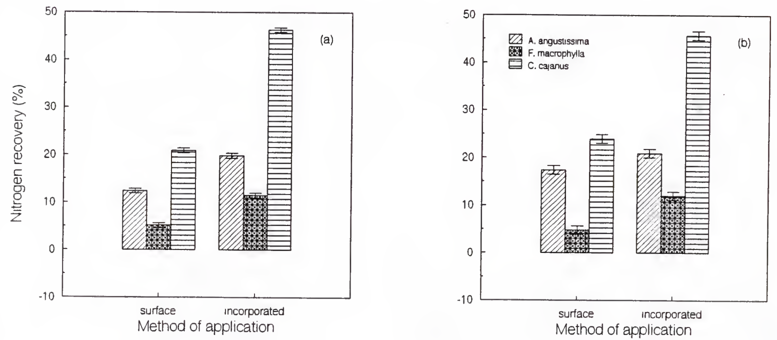


Figure 5.7 Percent nitrogen recovery by maize as affected by MPT species and method of pruning application at 12 weeks after planting on (a) Domboshava and (b) Makoholi soils.

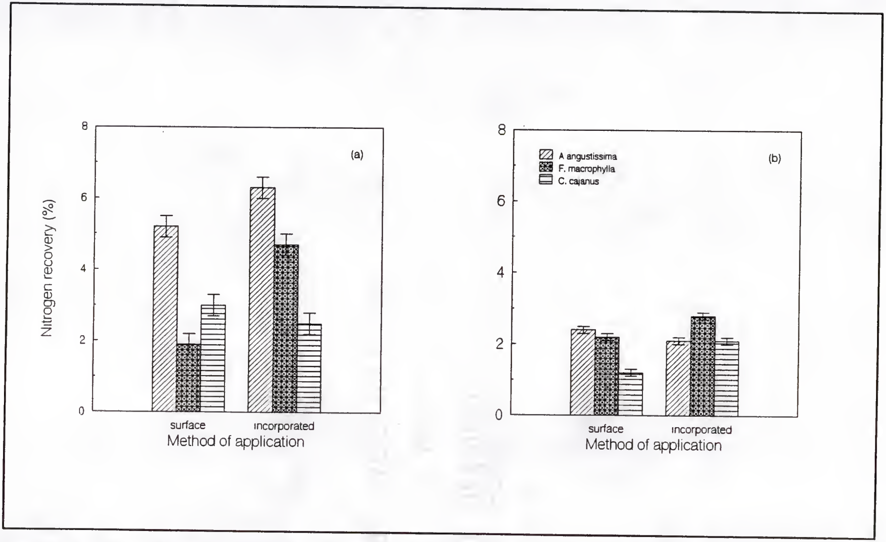


Figure 5.8 Percent nitrogen recovery by maize as affected by MPT species and method of pruning application at 18 weeks after planting on (a) Domboshava and (b) Makoholi soils.

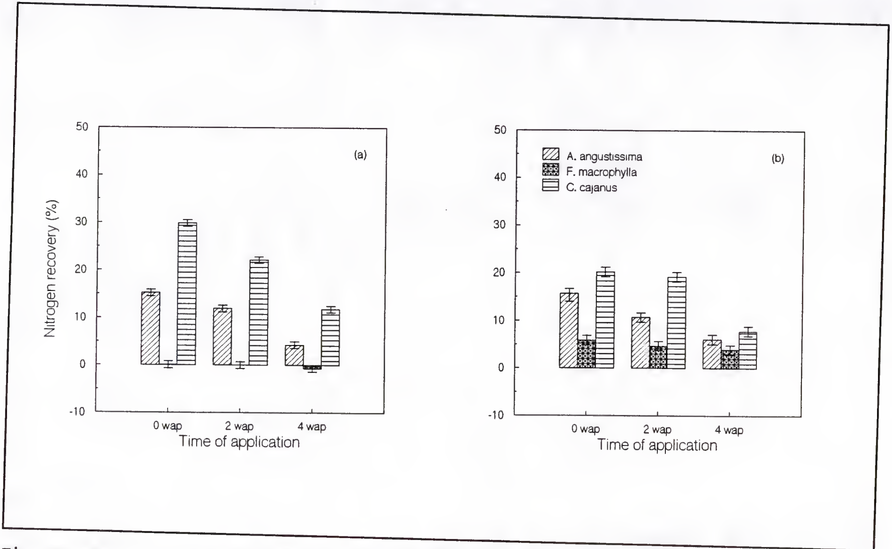


Figure 5.9 Percent nitrogen recovery by maize as affected by MPT species and time of pruning application at 6 weeks after planting on (a) Domboshava and (b) Makoholi soils.

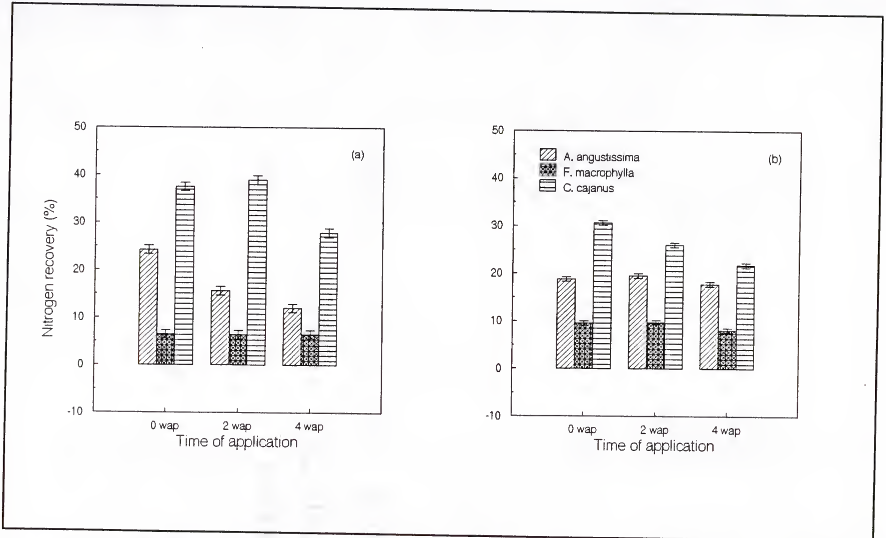


Figure 5.10 Percent nitrogen recovery by maize as affected by MPT species and time of pruning application at 9 weeks after planting on (a) Domboshava and (b) Makoholi soils.

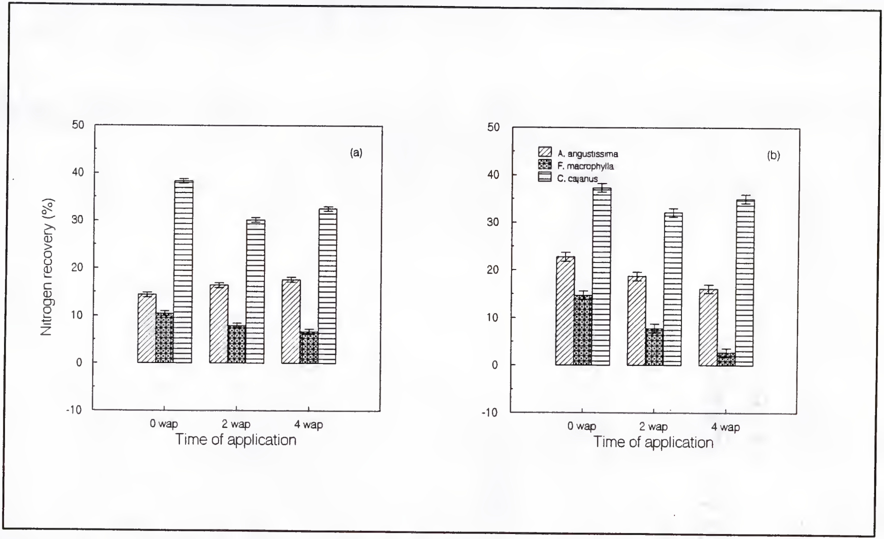


Figure 5.11 Percent nitrogen recovery by maize as affected by MPT species and time of pruning application at 12 weeks after planting on (a) Domboshava and (b) Makoholi soils.

When time of application x method interaction was considered, incorporation of prunings resulted in higher NIR compared to surface application (Tables 5.7 and 5.8). Within each application time, in general, application of prunings at planting gave higher NIR followed by 2 WAP and applying at 4 WAP gave the least. At 9 WAP sampling date, applying prunings at planting was equal to applying at 2 WAP in terms of NIR.

When prunings were surface applied on Domboshava, the order of NIR was, applying at planting > 4 WAP = 2 WAP, whereas with Makoholi soil applying at planting was > at 2 WAP = at 4 WAP at 12 WAP sampling date. With incorporation, applying at planting > 4 WAP > 2 WAP on Domboshava soil whereas on Makoholi soil at planting > 2 WAP = 4 WAP.

Incorporation of acacia and flemingia on Domboshava soil, and cajanus and flemingia on Makoholi soil gave significantly greater NIR with the second crop. However for cajanus on Domboshava soil, method of application had no significant effect on NIR whereas surface applied acacia gave higher NIR on Makoholi soil than incorporation.

Incorporation generally gave higher NIR than surface application at all application times. Within application methods, applying prunings at 4 WAP gave higher NIR > at 2 WAP > at planting with minor exceptions. In terms of species, acacia gave the highest NIR followed by flemingia and cajanus with few exceptions depending on the soil type

Table 5.7 The effect of method and time of pruning application on % nitrogen recovery: Domboshava soil.

| TIME OF APPL. | SAMPLING DATE | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 6 WAP | | 9 WAP | | 12 WAP | | 18 WAP | |
| | S * | I * | S | I | S | I | S | I |
| *0 WAP* | 11.5 | 18.0 | 13.3 | 27.6 | 14.3 | 27.8 | 2.5 | 3.3 |
| *2 WAP* | 6.6 | 16.1 | 13.6 | 26.9 | 11.8 | 24.3 | 3.7 | 4.7 |
| *4 WAP* | 2.1 | 7.9 | 7.1 | 23.7 | 12.3 | 25.5 | 3.9 | 5.5 |
| LSD (P < 0.0 | 1.2 | | 1.6 | | 0.7 | | 0.4 | |

Table 5.8 The effect of method x time of pruning application on % nitrogen recovery: Makoholi soil.

| TIME OF APPL. | SAMPLING DATE | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 6 WAP | | 9 WAP | | 12 WAP | | 18 WAP | |
| | S * | I * | S | I | S | I | S | I |
| *0 WAP* | 8.1 | 19.8 | 17.6 | 21.7 | 16.9 | 32.8 | 2.0 | 1.9 |
| *2 WAP* | 7.7 | 15.3 | 16.8 | 20.0 | 14.9 | 21.1 | 2.0 | 2.3 |
| *4 WAP* | 2.9 | 8.9 | 15.3 | 16.5 | 14.3 | 21.5 | 1.8 | 2.9 |
| LSD (P < 0.05) | 1.3 | | 0.6 | | 1.2 | | 0.2 | |

and time of application. With Domboshava soil when prunings were applied at different times, the order of response was acacia > flemingia > cajanus. However with Makoholi soil the order differed with each application time; at planting it was flemingia > acacia and cajanus; at 2 WAP it was flemingia > acacia > cajanus; and at 4 WAP acacia > flemingia > cajanus. Time of application had no effect on NIR for cajanus and flemingia on Makoholi soil.

## Discussion

The above results show that when MPT prunings are used as a source of N to a maize crop, pruning quality, species and management factors affect N uptake by maize.

There was an interaction of species and application method on maize shoot growth, N uptake and NIR. Incorporation of prunings gave higher N uptake and NIR than surface application. This could be attributed to greater rates of decomposition and N mineralization of incorporated prunings compared to those of surface-applied mulch. These results agree with those in Chapter 3, where incorporated prunings of acacia and cajanus had higher decomposition and N-release constants than surface-applied under field conditions. Greenhouse studies done by Kaufusi and Asghar (1990), and Ezenwa and Alasiri (1991) using the same species also found that N uptake by maize was higher with prunings incorporated than surface applied.

The low N uptake and NIR from surface applied prunings could be due also to N volatilization as ammonia, as suggested by Costa et al. (1990) and Janzen and McGinn (1991). Since this experiment was done in the greenhouse, moisture and temperature conditions could not have limited decomposition rates so much. The results of the study agreed with those obtained in the field (see Chapter 3) where incorporation of prunings gave higher N uptake, NIR and maize grain yield compared to surface application with cajanus and acacia.

Across application methods, MPT species showed differences in N uptake, NIR and shoot dry weight. Cajanus gave the highest N uptake, NIR and shoot dry weight followed by acacia and flemingia. This could be explained by the differences in pruning quality as shown in Table 5.2. Flemingia immobilized N in the Domboshava soil but not in the Makoholi soil. The low NIR of flemingia prunings could be associated with slow decomposition due to high % lignin and soluble polyphenols and low % N in the prunings (Table 5.2). This could have led to N immobilization as shown with Domboshava soil. This N immobilization by flemingia prunings was also shown in the incubation study reported in Chapter 2, where cajanus was shown to be releasing N quite fast compared to acacia (see Chapters 2 and 3).

The differences in N release patterns between the two soil types could be explained by inherent low soil fertility

from Makoholi (sandy soil) compared to Domboshava (sandy loam) (Table 5.2). Christensen (1985) also found no N immobilization in a sandy soil compared to a sandy loam with wheat straw. It may be that the Domboshava sandy loam soil had higher % C than the sandy Makoholi soil, perhaps leading to high microbial activity and high N mineralization rates.

Time of application affected NIR. Across MPT species, applying prunings at planting led to more efficient use of pruning N. Applying prunings at 2 or 4 WAP led to lower N uptake, NIR and shoot dry weight. Studies by Karlen et al. (1987, 1988) have shown that maize growth and N uptake are slow from emergence to 6 weeks after emergence, then the crop enters a period of rapid growth and N uptake until silking, followed by slow N uptake during grain filling, when N is reimmobolized from old leaves. Prunings applied at planting may release most of their N prior to peak N demand by maize at 6 to 12 WAP, resulting in more available N to the crop during this period. Applying prunings at 2 or 4 WAP may result in less N release before peak demand, hence lower maize N uptake and NIR. Results from the field experiment (Chapter 4), and Mulongoy et al. 1993, Kang and Mulongoy 1987, and Mulongoy 1987 also confirm that prunings applied at 2 or 4 WAP result in significantly lower NIR than those applied at planting.

The residual effects of pruning application on maize shoot dry weight, N uptake and NIR were affected by MPT

species x time of pruning application x method of pruning application. Across application methods, species and time of application had significant effects. Incorporation of prunings gave higher N uptake and NIR for cajanus, acacia and flemingia except on Makoholi soil where surface applied acacia prunings gave higher NIR compared to incorporated prunings. Acacia gave better residual effect > flemingia > cajanus. Cajanus decomposed so rapidly and released N so quickly that most of the N was used by the first maize crop with less residual effect on the second crop. MPT species such as acacia and flemingia, which were of medium- to low-quality, had slow N release patterns (see Tables 2.4 and 5.2, and Figures 2.1 and 2.2) and had greater residual effect on N uptake and NIR.

Applying prunings at 4 WAP produced the highest residual effect on NIR which was higher than at 2 WAP, in turn more than prunings applied at planting. The maize crop had its N demand peak from 6 WAP to 12 WAP. Prunings applied at planting and incorporated would release most of the N before the peak N demand period. However prunings applied at 4 WAP would have decomposed for 8 weeks at final harvest i.e., at 12 WAP. This could have created asynchrony between N supply from the prunings and peak N demand by maize resulting in available N for the second maize crop. The N was released during the time when maize was not in such a demand for N and hence high residual effect.

The NIR of the second maize crop ranged 1.5-6.0%. The low NIR of the second maize crop can be explained by differences in pruning quality, and time and method of pruning application. Prunings such as those of cajanus would release N very rapidly (Fig 2.1 and Table 2.4), and most of this N will be used by the current crop, leaving little residual N for the second crop. However, low-quality prunings like those of flemingia (Table 2.4 and 5.2) initially immobolize N, and later slowly release it (Figure 2.2). Such prunings would have higher NIR for the second crop. Prunings applied at 2 or 4 WAP release less N to the current crop, providing more residual N for subsequent crops (Figure 5.12).

The advantage to applying prunings of low quality would be the build up of soil organic matter pools which release N slowly over time. However application of high quality prunings such as those of cajanus would immediately benefit the current crop rather than the subsequent crop or build up soil organic matter pools (Jensen 1994, Janzen et al. 1990, and Harris et al. 1990). An interesting situation would be application of a mixture of cajanus and flemingia prunings. The flemingia prunings could potentially lead to soil organic matter build up, while the cajanus prunings could supply N for the current crop.

The recovery of N from MPT prunings as a source of N to maize can be significantly improved through manipulating MPT

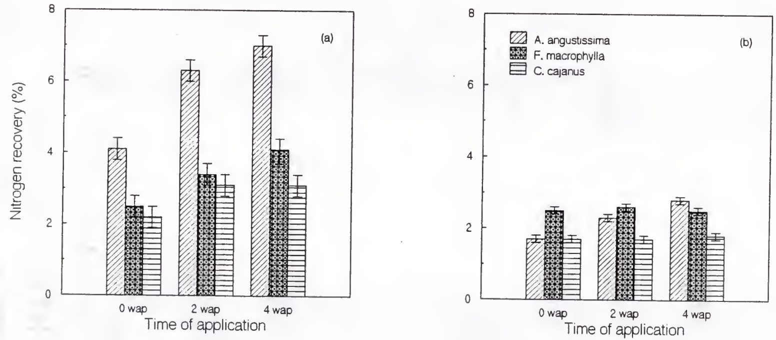


Figure 5.12 Percent nitrogen recovery by maize as affected by MPT species and time of pruning application at 18 weeks after planting on (a) Domboshava and (b) Makoholi soils.

species selection and time and method of pruning application. Incorporating prunings of different quality resulted in maize recovering almost twice the amount of N from the prunings. Prunings applied at planting gave the highest N uptake and NIR. Applying prunings at 4 WAP gave significantly better N uptake and NIR by the second crop than prunings applied at 2 WAP or at planting for most species. N uptake and NIR by maize were highest for cajanus, which produces high-quality prunings. Flemingia prunings were not a good source of N to the current crop.

The fate of released N could be more accurately assessed if $^{15}N$ is used to determine the relative amounts of N assimilated in microbial biomass from surface-applied and soil-incorporated prunings. The different $^{15}N$ proportions entering the soil microbial pool, soil mineral pool and organic N pools need to be measured under field conditions.

It must be borne in mind that these experiments were carried out in pots in the greenhouse, under ideal moisture conditions atypical of field conditions. N dynamics are restricted in pot environments and may not be comparable to field conditions. These results may be useful in initial screening of MPT prunings for important management factors in order to improve nitrogen use efficiency. Such greenhouse studies need to be confirmed by field studies before recommendations can be made to farmers.

# CHAPTER 6
# SUMMARY AND CONCLUSIONS

The overall objective of this study was to determine the effect of management and quality factors of multipurpose tree (MPT) prunings as an N source to maize. The study consisted of a laboratory incubation experiment, two field studies, and a greenhouse experiment. All experiments except the incubation experiment were conducted in Zimbabwe.

An underlining premise of the incubation experiment was that chemical quality indices such as lignin, NDF-N, polyphenols, polyphenol:N, and (lignin+polyphenol):N ratio could be used to predict N mineralization patterns of MPT prunings that are used as sources of N to the crop. Nitrogen recovery (NIR) was used as a measure of efficiency of N release from the prunings, where NIR is defined as:

$$NIR = \frac{N\ uptake\ treatment\ -\ N\ uptake\ control}{N\ applied} \times 100\%$$

A screening of seven species of MPTs that are used in agroforestry in Zimbabwe showed considerable variation in chemical quality indices among these species. Significant correlations between the quality indices and cumulative N mineralization support the hypothesis that N mineralization can be predicted from indices of prunings' chemical quality.

The prunings used in the study showed three main patterns of N release. These differences could be explained by the type and amount of soluble polyphenols, soluble carbohydrate and soluble nitrogen found in the prunings. The first pattern of rapid N release was exhibited by sesbania, cajanus and gliricidia. This pattern suggests available carbon and nitrogen in the prunings for use by the microbes. These prunings had low concentration of polyphenols, lignin and NDF-N. A second pattern of initial N immobilization followed by N release was shown by acacia, calliandra and leucaena. These prunings had high polyphenol concentration and some species like acacia had very high % NDF-N. The third pattern of N immobilization throughout the sampling period was shown by flemingia. Its prunings had high insoluble N in the form of NDF-N, lignin, and polyphenol concentrations, which could lead to N immobilization when these prunings are applied to the soil.

The N release patterns observed from these MPT prunings have several management implications. Prunings like those of sesbania, cajanus and gliricidia that are low in soluble polyphenols release N rapidly and make it available for crop growth in the short term. The N may be released so rapidly before peak N demand by the crop that it can potentially be lost through leaching and volatilization. Prunings high in lignin and polyphenols, like those of flemingia and acacia, may immobilize N and may not provide enough N for the

current season's growth. However, they may possibly lead to soil organic matter buildup which will ensure adequate N supply in the long term. A mixture of rapid-N-release and slow-N-release prunings could be used to achieve the objectives of N availability in the short term as well as long term.

N availability from the prunings (when applied as a source of N to field grown crops) could be manipulated by management factors such as quantity, method, and time of pruning application. To test this, two field studies were conducted using prunings of five (Chapter 3) and two (Chapter 4) MPT species, respectively. Also, the effect of two different soil types on NIR was studied in a greenhouse experiment using prunings of three MPTs (Chapter 5). Crop growth was expressed in dry matter yield at various stages of growth and grain yield.

Nitrogen uptake, nitrogen use efficiency and grain yield were improved by MPT pruning quality and method of pruning application. Incorporated prunings gave higher NIR compared to surface application with most MPT species. This was explained by higher decomposition and N release constants when prunings were incorporated than when they were surface applied. A possible reason for low NIR of surface applied prunings could be the loss of N through ammonia volatilization. It might be possible to reduce this loss by incorporating prunings. This is an area that needs

further research. In order to achieve synchrony between N supply from the prunings and peak N demand by maize, there should be large amounts of N released in the soil before peak demand for N by the crop. This situation was achieved by incorporating high quality prunings such as those of cajanus, leucaena and calliandra at planting. The effect of repeatedly applying prunings of different quality over a long period of time on soil organic matter and soil fertility needs further research.

Time of pruning application and pruning quality significantly improved N uptake, NIR and grain yield compared to the control treatments where prunings were not applied. Applying prunings of calliandra at planting was significantly better in terms of maize N uptake, NIR and maize grain yield compared to prunings applied at 2 or 4 weeks after planting. However, with leucaena prunings, time of application had no significant effect on maize N uptake, NIR and maize grain yield. This result may imply that these leucaena prunings were of sufficiently high quality so that enough N was released before the peak N demand by maize.

Mixing prunings of leucaena and calliandra had no effect on maize N uptake, NIR and grain compared to each species applied alone. This could be explained by the fact that the prunings did not differ sufficiently in their chemical composition to produce a synergistic effect on NIR. Also, split application of available prunings in time had no

effect on NIR compared to one-time application of the entire amount of prunings. The explanation for this could be that split-applied prunings could not release enough N to meet both microbial and plant N demand. An area of further research would be to examine how N released by prunings applied at different times is stored in different soil organic matter (SOM) pools and the residual effect on subsequent crops.

In the greenhouse experiment, soils from two sites, Makoholi and Domboshava, representing major agricultural areas of Zimbabwe were used. The former is an alfisol, and the latter is a psamment. There was an interaction of MPT pruning quality, method of application, and time of pruning application on shoot dry weight, nitrogen uptake and NIR of maize. This was observed on both Makoholi and Domboshava soils at different stages of crop growth. Incorporating prunings was better in terms of NIR compared to surface application with most MPTs and at different times of application. This could be explained by higher decomposition rate and N release of incorporated prunings than surface applied prunings. Nitrogen loss through ammonia volatilization could also have been less from incorporated prunings than from surface-applied prunings. This aspect needs further research as well.

Applying prunings at planting gave higher NIR across most MPT species and application methods. This effect was

more pronounced with high quality prunings such as those of cajanus compared to low quality prunings (e.g., flemingia). Prunings applied at planting released more N before peak N demand by maize, which started from 6 weeks after maize emergence. Applying prunings at 2 or 4 weeks after planting resulted in lower NIR. This could perhaps be because not enough N was released to meet peak N demand which started at 6 weeks after planting.

Residual effects on N uptake and NIR by subsequent maize crops were affected by MPT pruning quality, method, and time of pruning application on both soil types. Makoholi soil had lower NIR for the second crop compared to the Domboshava soil (3% vs 6%).

The results from these studies have shown that NIR of MPT prunings as a source of N to maize depends on pruning quality, and the method and time of pruning application, suggesting that NIR can be improved through relatively simple systems management techniques. The economic viability and biological sustainability of biomass transfer system needs to be assessed over a longer period compared to an alley cropping system in the semiarid tropics.

Based on the studies presented here, the following areas particularly merit further research:

- the amount of N released that is found in microbial biomass, soil organic matter, and inorganic pools;
- amount of N lost through leaching and volatilization;

- different soil organic matter pools built from application of prunings of different quality over a long period of time;
- the residual effects of prunings applied at different times or to subsequent crops; and
- how the above processes are affected by method of pruning application.

Such studies will inevitably need to use radioisotopes such as $^{15}N$.

## BIBLIOGRAPHY


Akobundu, I.O. and Okigbo, B.N. 1984. Preliminary evaluation of ground cover crops for use as live mulch in maize production. *Field Crops Research* 8:177-186.

Amato, M., Ladd, J.N., Ellington, A. and Walsgot, P. 1987. Decomposition of plant material in Australian soil: IV. Decomposition in site of $^{13}C$ and $^{15}N$ labelled legume and wheat materials in a range of Australian soils. *Australian Journal of Soil Research* 25:95-105.

Anderson, J.M. and Ingram, J.S.I. (eds.). 1990. *Tropical Soil Biology and Fertility: A Handbook of Methods*, 2nd ed. CAB International, Wallingford, Oxon, U.K.

Balasubramanian, V. and Sekayange, L. 1992. Five years of research on improved fallow in the semi-arid highlands of Rwanda. pp. 405-422 *In*: K. Mulongoy, M. Gueye, and D.S.C. Spencer (eds.), *Biological Nitrogen Fixation and Sustainability in Tropical Agriculture*. A Wiley-Sayce co-publication, New York, NY, USA and Exeter, U.K.

Batiano, A. and Mokwunye, A.Y. 1991. Role of manures and crop residues in alleviating soil fertility constraints to crop production. *Fertilizer Research* 29:117-125.

Becker, M., Ladha, J.K., Simpson, I.C. and Ottow, J.C.G. 1994. Parameters affecting residue nitrogen mineralization in flooded soils. *Soil Science Society of America Journal* 58:1666-1671.

Brown, L.R., Lenssen, N. and Kane, H. 1995. *Vital Signs 1995*. Worldwatch Institute, Washington, DC, USA.

Budelman, A. 1988. The decomposition of leaf mulches of *Leucaena leucocephala*, *Gliricidia sepium* and *Flemingia macrophylla* under humid tropical conditions. *Agroforestry Systems* 7:33-46.

Budelman, A. 1989. The performance of selected leaf mulches in temperature reduction and moisture conservation in the upper soil stratum. *Agroforestry Systems* 8:53-66.

Cataldo, D.A., Haroon, M., Schrader, L.E. and Young, V.L. 1975. Rapid calorometric determination of nitrate in plant tissue by titration of salicylic acid. *Communications in Soil Science and Plant Analysis* 6:71-80.

Christensen, B.T. 1985. Wheat and barley straw decomposition under feed conditions: Effect of soil type and plant cover on weight loss, nitrogen and potassium content. *Soil Biology and Biochemistry* 17:691-697.

Constantinide, M. and Fownes, S.H. 1994. Nitrogen mineralization from leaves and litter of tropical plants. Relationship to nitrogen, lignin and soluble polyphenol concentrations. *Soil Biology and Biochemistry* 26:49-55.

Costa, F.J.S.A., Bouldin, D.R., and Suhet, A.R. 1990. Evaluation of N recovery from mucuna placed on the surface or incorporated in a Brazilian Oxisol. *Plant and Soil* 124:91-96.

Cotnifo, M.F., Ineson, P. and Rowland, A.P. 1994. Decomposition of tree leaf litters grown under elevated $CO_2$: Effects of litter quality. *Plant and Soil* 163:121-130.

Dawra, R.K., Mukkar, H.S.P., and Singh, B. 1988. Protein binding capacity of microquantities of tannins. *Analytical Biochemistry* 170:50-73.

Dorich, R.A. and Nelson, D.W. 1982. Direct calometric measurement of ammonium in potassium chloride extracts in soil. *Soil Science Society of America Journal* 47:833-836.

Ezenwa, I.V. and Alasin, K.O. 1991. Use of leguminous tree leaves as a nutrient source for maize in a lateritic soil. *Nitrogen Fixing Tree Research Reports* 8:93-84.

Food and Agriculture Organization (FAO). 1990. New environmental threat: Declining soil fertility. *Land and Water Technical Newsletter* 34:6-7.

Fox, R.H., Myers, R.J.K. and Vallis, I. 1990. The nitrogen mineralization rate of legume residues in soil as influenced by their polyphenol, lignin and nitrogen contents. *Plant and Soil* 129:251-259.

Frankenberger, W.T. and Abdelmagid, H.M. 1985. Kinetics parameters of nitrogen mineralization rates of

leguminous crops incorporated into soil. *Plant and Soil* 87:257-271.

Goering, H.K. and Soest, P.J. van. 1970. Forage Fiber Analyses. U.S.D.A. Agricultural Handbook No. 379. U.S. Government Printing Office, Washington, DC, USA.

Handayanto, E., Cadisch, G. and Giller, K.E. 1994. Nitrogen release from prunings of hedgerow trees in relation to quality of the prunings and incubation method. *Plant and Soil* 160:237-248.

Handayanto, E., Nuraini, Y., Purnomosidi, P., Hanegraaf, M., Agterberg, G., Hassink, J., and Noordwijk, M. van. 1992. Decomposition rates of legume residues and N mineralization in an ultisol in Lampung. *Agrivita* 15:75-86.

Haslam, E. 1989. *Plant Polyphenols: Vegetable Tannins Revisited*. Cambridge University Press, Cambridge, U.K.

International Centre for Research in Agroforestry (ICRAF) 1992. *Annual Report 1991*. ICRAF, Nairobi, Kenya.

International Institute for Tropical Agriculture (IITA). 1986. Nitrogen contribution of hedgerow trees in alley cropping systems. pp. 27-28 *In: Annual Report and Research Highlights*. IITA, Ibadan, Nigeria.

Jama, B.A., Nair, P.K.R., and Rao, M.R. (in press). Productivity of hedgerow shrubs and maize under alleycropping and block planting systems in semiarid Kenya. *Agroforestry Systems*.

Jama-Adan, B. 1993. Soil Fertility and Soil Productivity Aspects of Alley Cropping *Leucaena leucocephala* and *Cassia siamea* Under Semi-arid Conditions at Machakos, Kenya. Ph.D. dissertation. University of Florida, Gainesville, FL, USA.

Janzen, H.H. and McGinn, S.M. 1991. Volatile loss of nitrogen during decomposition of legume green manure. *Soil Biology and Biochemistry* 23:291-297.

Janzen, H.H., Bole, J.B., Biederbeck, V.O. and Slinkard, A.E. 1990. Fate of N applied as green manure or ammonium fertilizer to soil subsequently cropped with spring wheat at three sites in Western Canada. *Canadian Journal of Soil Science* 70:313-323.

Kachaka, S., Vanlauvre, B. and Merekx, O. 1993. Decomposition and nitrogen mineralization of prunings

of different quality. pp. 199-203 *In*: K. Mulongoy and R. Merekx (eds.) *Soil Organic Matter Dynamics and Sustainability of Tropical Agriculture*. John Wiley and Sons, Chichester, U.K.

Kang, B.T. 1988. Nitrogen cycling in multiple cropping systems. pp. 333-348 *In*: J.R. Wilson (ed.) *Advances in Nitrogen Cycling in Agricultural Ecosystems*. CAB International, Wallingford, Oxon, U.K.

Kang, B.T. and Duguma, B. 1985. Nitorgen management in alley cropping systems. pp. 269-284 *In* B.T. Kang and J. Van der Heide (eds.) *Nitrogen Mangement in Farming Systems in Humid and Subhumid Tropics*. Institute for Soil Fertility, Haren, The Netherlands.

Kang, B.T. and Mulongoy, K. 1987. *Gliricidia sepium* as source of green manure in alley cropping system. pp 44-58 *In*: NFTA *Gliricidia sepium Management and Improvement*. Nitrogen Fixing Tree Association Special Publication 87-01. NFTA, Waimanalo, HI, USA.

Kang, B.T., Reynolds, L., and Atta-Krah, A.N. 1990. Alley farming. *Advances in Agronomy*. 43:315-359.

Kang, B.T., Wilson, G.F., and Sipkens, L. 1981. Alley cropping maize (*Zea mays* L.) and leucaena (*Leucaena leucocephala* Lam.) in Southern Nigeria. *Plant and Soil* 63:165-179.

Karlen, D.L., Flannery, R.L., and Sadler, E.J. 1987. Nutrient and dry matter accumulation rates for high yielding maize. *Journal of Plant Nutrition* 10:1409-1417.

Karlen, D.L., Flannery, R.L., and Sadler, E.J. 1988. Aerial accumulation and partitioning of nutrients by corn. *Agronomy Journal* 80:232-242.

Kaufusi, P. and Asghar, M. 1990. Effects of incorporating plant materials on corn growth. *Nitrogen Fixing Tree Research Reports* 8:81-82.

Kholdebaria, B. and Oertli, J.J. 1994. Nitrification: Interference by phenolic compounds. *Journal of Plant Nutrition* 17:1827-1837.

Kwesiga, F. and Coe, R. 1994. The effect of short rotation *Sesbania sesban* planted fallows on maize yield. *Forest Ecology and Management* 64:199-208.

Ladd, J.N., Amato, M., Jackson, R.B., and Butler, J.H.A. 1983. Utilization by wheat crops of nitrogen from legume residues decomposing in soils in the field. *Soil Biology and Biochemistry* 15:231-238.

McClure, J.W. 1979. The physiology of phenolic in plants. *Recent Advances in Phytochemistry* 12:525-556.

Meentemeyer, V.M. 1978. Microclimate and lignin control of litter decomposition rates. *Ecology* 59:465-472.

Melillo, J.M., Aber, J.D. and Muratore, J.F. 1982. Nitrogen and lignin control of hardwood leaf litter decomposition dynamics. *Ecology* 63:621-626.

Mugendi, D.N., Mochoge, B.O., Coulson, C.L., Stigter, C.J., and Sang, F.K. 1994. Decomposition of *Cassia siamea* loppings in semiarid Machakos, Kenya. *Arid Soil Research and Rehabilitation* 8:363-372.

Muller, R.N., Kalisz, P.I. and Kimmerer, T.W. 1987. Intraspecific vanalia in production of astringent phenolics over a vegetation resource availability gradient. *Oecologia* 72:211-215.

Mulongoy, K. 1986. Potential of *Sesbania rostrata* (Brem.) as nitrogen source in alley cropping systems. *Biological Agriculture and Horticulture* 3:341-346.

Mulongoy, K. and Akobundu, I.O. 1992. Agronomic and economic benefits of N contributed by legumes in live-mulch and alley cropping systems. *IITA Research* 4:12-15.

Mulongoy, K. and Meersh, M.K. van der. 1988. Nitrogen contribution by leucaena (*Leucaena leucocephala*) prunings to maize in an alley cropping system. *Biology and Fertility of Soils* 6:282-285.

Mulongoy, K. and Sanginga, M.K. 1990. Nitrogen contribution by leucaena in alley cropping system. *ITTA Research* 1:14-17.

Mulongoy, K., Ibewono, E.B., Oseni, O., Kulumba, N., Opara-Nadi, A.O., and Osobuni, O. 1993. Effect of management practices on alley cropped maize utilization of nitrogen derived from prunings on a degraded alfisol in southwest Nigeria. pp. 223-230 *In*: K. Mulongoy and R. Merckx (eds.) *Soil Organic Matter Dynamics and Sustainability of Tropical Agriculture*. John Wiley & Sons Ltd., Chichester, U.K.

Myers, R.J.K., Palm, C.A., Cuevas, E., Gunakilleke, I.U.N., and Brossard, M. 1994. The synchronisation of nutrient mineralisation and plant nutrient demand. pp. 81-116 *In:* Woomer, P.L. and M.G. Swift (eds.) *Biological Management of Tropical Soil Fertility*. A Wiley-Sayce co-publication, New York, NY, USA and Exeter, U.K.

Nair. P.K.R., Rao, M.R., and Fernandes, E.C.M. 1994. Tree-crop interactions in sustainable agroforestry systems. pp. 110-137 *In*: S.M. Virmani and G.S. Sekhon (eds.) *Soil Technology for Sustainable Agriculture*. Symposium VIa, XV World Soils Congress, Acapulco, Mexico.

Nair, P.K.R. 1984. *Soil Productivity Aspects of Agroforestry*. ICRAF, Nairobi, Kenya.

Nair, P.K.R. 1993. *An Introduction to Agroforestry*. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Nye, P.H. and Greenland, D.J. 1960. The soil under shifting cultivation. Technical communication 51. Commonwealth Bureau of Soils, Harpender, U.K.

Oglesby, K. and Fownes, J.H. 1992. Effects of chemical composition on nitrogen mineralization from green manures of seven tropical leguminous trees. *Plant and Soil* 143:127-132.

Ong, C.K. 1994. Alley cropping—ecological pie in the sky. *Agroforestry Today* 6:8-10.

Palm, C.A. and Sanchez, P.A. 1990. Decomposition and nutrient release patterns of the leaves of three tropical legumes. *Biotropica* 22:330-338.

Palm, C.A. and Sanchez, P.A. 1991. Nitrogen release from the leaves of some tropical legumes as affected by their lignin and polyphenolic contents. *Soil Biology and Biochemistry* 23:83-88.

Population Reference Bureau (PRB). 1995. *World Population Data Sheet*. PRB, Washington, DC, USA.

Reed, J.D., Horvath, P.J., Allen, M.S. and Soest, P.J. van. 1985a. Gravimetric determination of soluble phenolics including tannins from leaves by precipitation with trivalent ytterbium. *Journal of Science in Food and Agriculture* 36:255-261.

Reed, J.D., McDowell, R.E., Soest, P.J. van, and Horvath, P.J. 1982. Condensed tannin a factor limiting the use

of cassava forage. *Journal of Science in Food and Agriculture* 33:213-220.

Reed, M.D., Kang, B.T. and Wilson, G.F. 1985b. Use of *Leucaena leucocephala* leaves as a nitrogen source for crop production. *Fertilizer Research* 8:107-116.

Sanchez, P.A. 1976. *Properties and Management of Soils in the Tropics*. John Wiley and Sons, New York, NY, USA.

Sandhu, J.M., Simha, M. and Ambasht, R.S. 1990. Nitrogen release from decomposing litter of *Leucaena leucocephala* in the dry tropics. *Soil Biology and Biochemistry* 22:859-863.

SAS Institute. 1982. *SAS User's Guide*. SAS Institute, Cary, NC, USA.

Schroth, G., Zech, W., and Heimann, G. 1992. Mulch decomposition under agroforestry conditions in a sub humid tropical system savanna, processes and influence of perennial plants. *Plant and Soil* 147:1-11.

Sorensen, L.H. 1975. The influence of clay on the rate of decay of amino acid metabolites aynthesized in soil during decomposition of cellulose. *Soil Biology and Biochemistry* 7:171-177.

Spain, A. 1990. Influence of environmental conditions and some soil chemical properties on the carbon and nitrogen contents of some tropical Australian rainforest soils. *Australian Journal of Soil Research* 28:825-839.

Stevenson, F.J. 1982. *Humus Chemistry: Genesis, Composition, Reactions*. John Wiley & Sons, New York, NY, USA.

Stump, L.M. and Binkley, D. 1993. Relationship between litter quality and nitrogen availability in the Rocky Mountains forest. *Canadian Journal of Forest Research* 23:492-502.

Swain, T. 1979. Tannin and lignin. pp. 657-682 *In*: G.A. Rosenthal and D.H. Janzen (eds.), *Herbivores: Their Interaction with Secondary Plant Metabolites*. Academic Press, New York, NY, USA.

Swift, M.J. (ed.) 1987. Tropical soil biology and fertility. Interregional Resource Planning Workshop. Special Issue 13, *Biology International*. IUBS, Paris, France.

Swift, M.J., Heal, O.W. and Anderson, J.M. 1979. *Decomposition in Terrestial Ecosystems*. Studies in Ecology, volume 5. University of California Press. Berkeley, CA, USA.

Szott, L.T. and Kass, D.C. 1993. Fertilizers in agroforestry systems. *Agroforestry Systems* 23:157-176.

Taylor, B.K., Parkinson, D., and Parsons, F.J. 1989. Nitrogen and lignin content as predictors of litter decay rates: A microcosm test. *Ecology* 70:97-104.

Thomas, R.J. and Asakawa, N.M. 1993. Decomposition of leaf litter from tropical forage grasses and legumes. *Soil and Biology and Biochemistry* 25:1351-1361.

Thorup-Kristensen, K. 1994. An easy pot incubation method for measuring nitrogen mineralization from easily decomposable organic material under well defined conditions. *Fertilizer Research* 38:239-247.

Tian, G., Kang, B.T., and Brussaard, L. 1992a. Effects of chemical composition on N, Ca and Mg release during incubation of leaves from selected agroforestry and fallow species. *Biogeochemistry* 16:103-119.

Tian, G., Kang, B.T., and Brussaard, L. 1992b. Biological effects of plant residues with contrasting chemical composition under humid tropical conditions — decomposition and nutrient release. *Soil Biology and Biochemistry* 24:1051-1060.

Tomar, V.P.S., Narain, P. and Dadhwal, K.S. 1992. Effects of perennial mulches on moisture conservation and soil building properties through agroforestry. *Agroforestry Systems* 19:241-252.

Vallis, I. and Jones, R.J. 1973. Net mineralization of nitrogen in leaves and leaf litter of *Desmodium intertum* and *Phaseolus artropurpureus* mixed with soil. *Soil Biology and Biochemistry* 5:391-398.

Vlek, P.L.G. 1990. The role of fertilizers in sustaining agriculture in sub-Saharan Africa. *Fertilizer Research* 26:327-339.

Weider, R.K. and Lang. G.E. 1982. A critique of the analytical methods used in examining decomposition data obtained from litter bags. *Ecology* 63:1636-1642.

Wilson, D.O. and Hardgrove, H.L. 1986. Release of nitrogen from crimson clover residue under two tillage systems. *Soil Science Society of America Journal* 50:1251-1254.

Wilson, G.F., Kang, B.T., and Mulongoy, K. 1986. Alley cropping: Trees as sources of green manure and mulch in the tropics. *Biological Agriculture and Horticulture* 3:251-267.

Xhu, Z., Liu, C., and Jiang, B. 1984. Mineralization of organic nitrogen in some paddy soils of China in organic matter and rice. pp 259-272. IRRI. Los Banos, Laguna.

Xu, Z.H., Saffigna, P.G., Myers, R.J.K., and Chapman, A.L. 1993. Nitrogen cycling in leucaena (*Leucaena leucocephala*) alley cropping in semiarid tropics. I. Mineralization of nitrogen from leucaena residues. *Plant and Soil* 148:63-72.

Yamoah, C.F., Agboola, A.A. and Mulongoy, K. 1986. Decomposition, nitrogen release and weed control by prunings of selected alley cropping shrubs. *Agroforestry Systems* 4:239-246.

Young, A. 1989. *Agroforestry for Soil Conservation*. CAB International, Wallingford, Oxon, U.K.

Zosya, A.K.N. and Keerthisinghe-Upasena, S.H. 1990. Effect of *Leucaena leucocephala* (Lam.) DeWit as a green manure on nitrogen uptake and yield of rice. *Biology and Fertility of Soils* 9:68-70.

## BIOGRAPHICAL SKETCH

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Between 1987-1990 Paramu attended the University of London, Wye College, U.K., where he obtained an MSc degree in applied plant sciences. In 1990, he obtained another MSc degree from University of London Wye College in agricultural development.

In 1991 Paramu started studies at the University of Florida for a doctoral degree in forest resources and conservation with a specialization in agroforestry.

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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